Mechanical Reliability Analysis and Optimization Design Method Based on Evidence Theory

Xiaoxing Yang 1,a,*

1Mechanical and Electrical Engineering, College of Information, Shanxi Agricultural University, Taigu 030800, Shanxi, China

*Corresponding author e-mail: yangxiaoxing2020@163.com

Abstract. The analysis and design of mechanical structures and systems has a long and in-depth research history, and has achieved fruitful results. In fact, in the traditional analysis and design of mechanical structures and systems, people have found that there are a lot of uncertainties in the disciplines of system science, transportation science, and management science. It is difficult for traditional deterministic design methods to effectively deal with this type of problems. Uncertainty issues, such as the uncertainty of the shape and size of the structure due to the influence of processing technology, processing equipment, environmental factors and human factors in the manufacturing process, these inaccurate and uncertain information mainly come from the processing technology , Processing equipment, environmental factors, and man-made factors, and evidence theory can effectively model the problem of cognitive uncertainty in engineering, using probability intervals composed of credibility and likelihood to describe the cognitive uncertainty brought about by Impact. This article introduces the basic concepts of evidence theory and the basic process of reliability analysis of conventional evidence theory, and optimizes it to a certain extent. Then, this paper uses the optimization method and conventional methods of this paper to deal with a practical engineering problem, and compares the results. The final research results show that the optimization method in this paper is more effective than conventional methods, and it is concluded that the theory of evidence is indeed applicable to mechanical engineering, and it can effectively analyze the reliability of machinery.

Keywords: Evidence Theory, Optimization Design, Traditional Engineering Design, Method Reliability

1. Introduction

In traditional engineering design and safety analysis, engineering designers usually treat things as accurate, and use deterministic mathematical methods to solve and analyze. This method has solved human production and development in the past century. A series of questions. In the mid-1960s, people found that there were a large number of uncertainties in disciplines such as mechanical engineering science, transportation science, and information engineering science, and the traditional deterministic design method was difficult to effectively deal with such uncertainties. For example, due to the influence of processing technology, processing equipment, environmental factors and human factors in the process of manufacturing, there is
uncertainty in the shape and size of the structure, and due to the effects of processing technology, processing equipment, environmental factors and human factors in the process of manufacturing. As a result, there is uncertainty in the shape and size of the structure. For this reason, early engineers introduced the safety factor method, which used a certain safety factor to consider the impact of all uncertain factors on the system in the design process. However, the size of the safety factor needs to be selected based on subjective experience. The influence of many uncertain factors in the project cannot be considered quantitatively. The safety degree contained in it cannot be scientifically explained. For engineering safety and reliability, the choice of safety factor is usually very conservative, which leads to the uneconomical of the engineering structure and wastes a lot of social resources. Sometimes this overly conservative structure is even inappropriate or difficult to achieve. In addition, if the selected safety factor is not appropriate, it may also lead to the failure of the engineering structure, resulting in huge losses of the structure itself and people's lives and property.

The reliability design method developed in recent decades is an advanced design method. It considers various uncertain factors in the subsequent design, manufacture, use and maintenance of the structure from the initial stage of the design. It is a kind of Design method of whole life cycle [1]. Compared with the traditional deterministic design method and safety factor method, the reliability design method chooses a better balance point between economy and safety. At present, the reliability design method is mainly based on the probability theory, and the reliability index is a series of structural analysis methods, which can effectively deal with random uncertainty, which is called stochastic reliability analysis method [2]. Stochastic uncertainty is caused by insufficient causality, it is caused by the objective physical conditions of the system itself, and it cannot be reduced as the cognitive level increases or the experimental data increases [3].

This paper analyzes and studies the methods used in mechanical reliability in traditional industrial design in recent years, analyzes the problems such as load uncertainty, model uncertainty, etc. in some methods currently used, and proposes and proves it shows the applicability of evidence theory in this problem.

2. Method

2.1 Stochastic reliability method

The stochastic reliability method requires sufficient sample information to build an accurate probability distribution, and requires sufficient knowledge of uncertainty, which puts harsh requirements on the investigation and statistics of previous uncertainty information [4]. For some large and complex structures, it is difficult to build accurate probability distributions of uncertain variables due to the constraints of available resources such as existing knowledge, test budgets, time, etc. If the probability distributions of artificial variables are assumed, it may bring larger errors have also led to the limitations of the probabilistic method in some engineering applications [5-6]. This kind of cognitive uncertainty, which is restricted by the level of knowledge, means of understanding, information resources, natural and social environment, is called cognitive uncertainty, also known as subjective uncertainty. Cognition to reduce its degree of uncertainty [7]. The typical cognitive uncertainty stems from the increasing number of large-scale and complex systems in engineering, making data collection very expensive, and the rare failure modes in high-reliability systems making it difficult to collect data. The changing test environment makes the data collected inaccurate [8].

2.2 Evidence theory

At present, the modeling theories of cognitive uncertainty mainly include possibility theory, fuzzy set theory, model theory and evidence theory, etc. [9]. Studies have shown that evidence theory is a more general model of cognitive uncertainty modeling. Its axiom structure is more flexible than probability theory, so it has strong modeling and analysis capabilities, and is capable of analyzing incomplete and uncertain information. Unreliable information and even conflict information should be reasonably described and processed. In addition, the way in which evidence theory describes cognitive uncertainty is more in line with people's thinking habits and engineering phenomena. Therefore, in recent years, it has been widely used in uncertainty research in various engineering fields. Determine the problem for modeling, and use the probability interval composed of credibility and plausibility to describe the impact of cognitive uncertainty.
2.3 method optimization
Evidence theory reliability analysis requires extreme value analysis on each focal element. When the number of uncertain variables and variable focal elements is large, the "calculation explosion phenomenon" is prone to occur, and computing efficiency has become one of the main technical bottlenecks that limit its application [12]. The proxy model of the limit state equation can be constructed in an appropriate way, which can improve the calculation efficiency of the reliability analysis of evidence theory [13]. This article uses the recognition framework to explore this problem. The recognition framework is similar to the random variable sample space in probability theory. It consists of a limited number of basic elements, usually represented by \( X \). The limit state equation is used as follows:

\[
g(X) = \exp(0.2X_1 + 1.4) - X_2
\]

Use this equation to calculate and analyze engineering problems.

3. Experiment

3.1 Experimental Object
The purpose of mechanical reliability design is to estimate or predict the product's operating ability, state or life under the specified working conditions during the development stage of mechanical products, to point out and eliminate the weak links of the product, and to ensure the required reliability of the product. For mechanical products, reliability issues are closely related to personal safety, economic benefits and social benefits. Therefore, the safety and reliability of mechanical products is one of the main purposes of engineering design. Reliability is the quality that takes time into consideration, and more and more mechanical products are required to have reliability indicators. Therefore, it is undoubtedly necessary to deepen the comprehensive understanding of conventional design and promote reliability technology to improve the quality of products. Obviously, it is imperative to conduct research on reliability technology of mechanical products. This article discusses it based on evidence theory.

3.2 Experimental Methods
The research content and research ideas of this paper are to be developed from the following three aspects: first, develop an efficient and accurate evidence theory reliability analysis method; second, study the common random and cognitive mixed reliability problems in engineering, and efficiently solve them. This problem has important engineering significance: Finally, the reliability assessment method is applied to chemical design, and an efficient optimization algorithm is developed to improve the engineering practicability of evidence theory.

4. Discussion

4.1 Reliability error analysis
According to the characteristics of evidence theory, a proxy model is constructed, which can replace the real limit state equation for reliability analysis. In addition, scholars at home and abroad have also conducted some explorations on the application of different types of agent models in the reliability analysis of evidence theory, and have achieved good results in terms of efficiency improvement. However, due to the introduction of the agent model, the reliability analysis results of evidence theory may still produce large errors. In addition, due to the discrete nature of the evidence variables, their error sources are significantly different from those of random reliability analysis. Therefore, different error control strategies than random reliability are needed. Table 1 compares the conclusions of experiments using different methods:

| Table 1. Comparison of calculation efficiency between conventional reliability error analysis methods and optimization methods |
The number of invocations of the limit state equation of this method $n^2$ is calculated as follows:

| Method | Number of conventional state limit state equation calls $n_1$ | Computational efficiency $(n_1/n^2 \times 100\%)$ |
|--------|-------------------------------------------------------------|---------------------------------------------------|
|        | 73                                                          | 29%                                               |
|        | 73                                                          | 32%                                               |
|        | 73                                                          | 37%                                               |
|        | 73                                                          | 34%                                               |
|        | 73                                                          | 41%                                               |
|        | 73                                                          | 36%                                               |

It can be seen that the calculation amount of the optimization method in this paper is only 29% -41% of the conventional method, which is significantly better than the conventional method.

4.2 Optimization method and traditional method in this paper

According to the collected calculations for the same engineering problem, the traditional method and the traditional method optimized in this paper are used to calculate. The results are shown in Figure 1.

Figure 1. Comparison of calculation accuracy between the design method of this paper and the traditional method

4.3 Optimization method recommendations

This paper proposes an optimization design method based on the reliability of evidence theory. Without approximating the collection of additional information, an approximate gradient of the truth degree of evidence theory is constructed. The response surface is continuously updated with the design point iteration, which improves the calculation efficiency and ensures the accuracy of the chemical results. The tolerance correction strategy for the reliability analysis of evidence theory based on the agent model proposed in this paper is currently incomplete, and there is still room for further improvement in the selection of focus elements, tolerance value selection and result correction, so as to effectively ensure the agent model Analysis accuracy and efficiency. The evidence structure response and reliability analysis presented in this article are based on the premise that the uncertain variables are independent of each other in the existing evidence theory research. In the future, we should fully consider the correlation between the cognitive uncertainty variables and be reliable for the structure. Sexual impact. In addition, future research on cognitive uncertainty should also be extended to time-varying problems, system reliability problems, and spatial field problems to systematically analyze the theory of cognitive uncertainty analysis. The reliability optimization algorithm based on the evidence theory proposed in this paper constructs an approximate gradient of plausibility through homogenization, so that the gradient-based optimization algorithm can be used for optimization design, but the double-layer nested optimization process cannot be solved.

5. Conclusions
Due to the limitation of subjective and objective conditions, there are a large number of cognitive uncertainties in the structure or system. It is often difficult to obtain sufficient test sample information to build its accurate probability distribution function. Traditional probability theory deals with this type of cognitive instability. Deterministic problems can lead to poor results or even large errors. Therefore, studying other non-probabilistic methods to deal with cognitive uncertainty has certain theoretical significance and engineering application value. This paper further studies the reliability analysis and optimization design of evidence theory from different perspectives and levels, and finally verifies that the optimization method proposed in this article can significantly improve the calculation efficiency under the premise of ensuring accuracy.

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