Product Evaluation in Stages Based on Robust Design
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Abstract. Based on the study and analysis of product design evaluation, structure model of product evaluation in stages based on robust design is presented, and the key technologies are studied. Robust design aims to develop a product that satisfies design requirements while ensuring minimal effects of environmental variability on product performance. The different methods of robust design are applied in product evaluate according to design stage characteristics. Based on mechanical transmission design, a design evaluation system is implemented with the computer. The system is help for concurrent product development in whole life cycle.

Introduction
Successful manufactured products rely on the best design and performance. So the comprehensive evaluation of product design is very important, which can evaluate every aspect that influences design quality with all-round, multi-level, multi-objective methods in the concurrent product design [1]. In the design phase, through the prediction and estimation of the products comprehensive performance, design scheme is evaluated scientifically from technical and economical angle. Designers can know the effect of design decision on the performance and discover and solve the problems as early as possible, which can lead to speed up the design process, to achieve design optimization, and to improve product comprehensive competitiveness.

Technical and economic indexes of product evaluation will be different in different stage of product design, so the comprehensive evaluation model and method will be correspondingly different. Recently, robust design methods are adopted widely in Japan and Europe. One of the robust design methods is called the Taguchi method, namely the three-design [2]. It divides the design process into three stages: system design, parameter design and tolerance design. System design is the conceptual design stage where the system configuration is developed. Parameter design gains the optimal combination of parameters that reduces the system sensitivity to noise, thereby enhancing the system’s robustness. Tolerance design specifies the allowable deviations in the parameter values, loosening tolerances if possible and tightening tolerances if necessary. Therefore, in this paper, product comprehensive evaluation of the whole life cycle based on the theories of robust design is put forward. And evaluation system of mechanical transmission is developed with VC++ language and SQL database.

Product Evaluation Model in Stages
As we all know, product evaluation in the different design stage involves a variety of complex decision problems. Therefore, it is necessary to build a suitable comprehensive evaluation from different aspects in order to improve the quality of product. The evaluation model in stages is shown in Fig. 1.

According to the Taguchi method, specific stages of comprehensive evaluation include scheme design, detailed design and process design. And then related product evaluation information must be determined, which include the specific target, specific object, specific requirements and evaluation methods. The specific target should reflect technological, economical and social performances. The specific object refers to the different design scheme. The specific requirements include the time requirement, accuracy requirement and product evaluation levels. According to the specific
requirements and targets, evaluation methods can be divided into qualitative evaluation, quantitative evaluation, analogy evaluation, generative evaluation, etc. And then different evaluation models can solved and fed back the result to decide whether the initial scheme is changed or not.

The whole evaluation model in stages is executed by collaborative control. Collaborative control is a kind of interactive mode, which can complete many tasks, such as dispatching user activity, distributing shared resources and so on. Through the collaborative control mechanism, collaborative individual activities are organized closely.

![Model for product evaluation in stages](image)

**Fig. 1** Model for product evaluation in stages

**Key Technologies**

**Scheme Design Stage.** Scheme design plays an important role in the whole design process, which determines the product performance, cost and other indicators. At this stage, the designers should correctly understand the users' requirements, and apply the engineering and scientific knowledge to present a suitable design scheme at the lowest cost. However, the designers often give qualitative evaluation depending on their experience in terms of advantages and disadvantages of design schemes. As a usual, the evaluation result is one-sided, subjective and lack of adequate theoretical basis.

For example, in the mechanical transmission design, there may be multiple schemes for a given design conditions. Under the premise of meeting performance, designers evaluate the transmission scheme from technical and economic aspects, such as volume, technology, service, cost, time, and so on. These goals are contradictory and difficult to be satisfied at the same time, so a design proposal is made under the balance between different design targets. Moreover, the evaluation information is with strong uncertainties. Several fluctuant information sources should be given with full consideration in order to get the most reasonable evaluation results. Therefore, if the factor fluctuation that affects the evaluation result is taken into account, the evaluation quality can be assured. Meanwhile, considering a large number of fuzzy decision-making indexes, fuzzy robustness analyzing method is applied in scheme design [3, 4]. Namely, according to the design demand, the overall performance scheme and quality indexes are determined. Fuzzy robust analysis and comprehensive evaluation are used in the different schemes. Finally, scheme with better robustness is obtained, which can prepare for parameter design in further.

**Detailed Design Stage.** Parameter and tolerance design is the core in detailed design stage. From the engineering application point of view, parameter and tolerance design are considered together in robust optimal design system. Reasonable design variables are chosen so that the product performance is insensitivity to noise and reducing cost to minimum. Different models will be chosen according to the different design problem. If the design deviation can be determined, fixed tolerance model should be used. If the deviation cannot be determined, but need to consider the effect of tolerance for quality robustness, variable tolerance model should be adopted. The compound discrete genetic algorithm is applied as the solution algorithm. Finally the best combination of parameters and tolerance will be acquired and the results are stored into the relevant database for easy management and application.
In order to explain the obtained result reasonable and reliability, the result evaluation contains two parts in this system. One is convergence analysis of the results. The program control and visual analysis method are mainly adopted. The optimal process can be simulated by the curve graph that shows whether the results convergent or not. Another is correctness and advantage analysis of robust design result. The robust design result and the other optimization results are compared by data visual analysis, and then establish the digital prototype to analyze and evaluate whether the design result could meet the requirements and target or not. If the results are not ideal, it must be redesign. The structure diagram of the detailed design of drive machinery is as shown in Fig. 2.

Process Design Stage. It mainly includes two parts: allocation of process tolerance and reasonable configuration of procedure. In traditional process tolerance design, manual graphic solution is adopted to testify the relations between design tolerance and process tolerance, which is complex and easier to error. Using robust design in the process design, the maximum process tolerance and the best process routing will be designed based on economy and rationality. In this research, according to the design tolerance of parts, quality loss and the cost of various processing methods, cost-tolerance robustness optimization model is established, which target function is the minimum cost of manufacture and quality loss in order to optimize the process tolerances.

Analysis and evaluation in this stage includes the calculation of product comprehensive cost fuzzy quality loss. Due to fuzziness in the product quality and evaluation, the fuzzy set theory is introduced into the tolerance robust design. The smaller fuzzy quality loss is, the better the quality of the product is.

Applications

The product evaluation system in stages is developed with VC++ language and SQL database, by which the complex calculation was fulfilled with computer automatically. The example introduces the transmission design for the chemical equipment. According to the design requirements, 3 kinds of transmission scheme are considered: belt drive with single gear drive, worm drive and two-stage helical gear drive.

At First, selection of transmission scheme is done. Save the design information into the product database. Determine the evaluation indexes from technical and economic aspects. And then fuzzy robustness calculation is done. Through analysis of three kinds of transmission scheme, the final results are obtained. The membership degree of every scheme was 0.83, 0.61 and 0.88; variance of the membership degree was 0.00008079, 0.0000833, and 0.0000721, respectively. As shown by the obtained results, the membership degree of the third scheme is biggest and variance is smallest, which indicates that this scheme is the best and has higher performance in disturb resistance. Therefore, the third scheme, namely two-stage helical gear drive, is selected.

Secondly, enter into the detailed design module. The gear, shaft, bearings and other parts are calculated using robust design method. In this example, a helical gear transmission is designed [5]. Design parameters are input to the parameter setting interface, as shown in Fig.3, and then click the...
button “Optimum model” to choose the robust optimization model. The genetic algorithm is applied as the solution algorithm to obtain the best parameters. The solutions of optimization are shown in Table 1. As a comparison, the result of optimal design and the traditional design are also presented in the table. It is shown that the optimal effect is very obvious. The volume acquired by robust design is the smallest, and the result can improve the robustness of design quality.

![Fig. 3 Parameters input](image)

<table>
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<th>β</th>
<th>z₁</th>
<th>z₂</th>
<th>mₚ</th>
<th>ψₜ</th>
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<td>81</td>
<td>2.5</td>
<td>1.31</td>
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</table>

**Conclusions**

In the process of design, the evaluation information is strong uncertainties. Crucial problems in noise and vibration of the product performance are rarely considered. Therefore, it is necessary that fluctuant information sources are considered fully in order to get the most reasonable evaluation results. In this paper, the theory of robust design is applied in product evaluation. Product evaluation model in stages is put forward according to the design stage characteristics and the key technologies are discussed. Finally, an example of transmission design is used to demonstrate the application of these techniques. It is proved that the evaluation system is favorable for reducing production costs, improving product quality and shortening the product development cycle.

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**References**


