Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 53 (2016) 107 – 112

www.elsevier.com/locate/procedia

The 10th International Conference on Axiomatic Design, ICAD 2016

Research progress analysis of reliability design method based on axiomatic design theory

Jiang Shao*, Fengming Lu, Chenhui Zeng, Ming Xu

China Aero Poly-technology Establishment, Beijing, China

* Corresponding author. Tel.:+86-010-8438-0277; fax: +86-010-6464-9893. *E-mail address:* saviola80@sina.com

Abstract

With the increasing complexity of the product, the conventional reliability design methods can hardly support the realization of high reliability requirements, and how to carry out high reliability design has become the bottleneck problem which is urgent to be solved in the product development. As a conceptual decision design method of product design, Axiomatic Design is combined with reliability design, which provides a new way to solve the problem of high reliability design of products. This paper analyzes the common reliability design methods and the existed problems. The concepts of Axiomatic Design theory such as the independence axiom and information axiom are introduced. The complexity theory and relationship between complexity and reliability design are reviewed. The research progresses related to the reliability Axiomatic Design method are intensively analyzed. A kind of research thought of using Axiomatic Design theory to solve reliability design problems is proposed. Finally the research trends are prospected.

Peer-review under responsibility of the scientific committee of The 10th International Conference on Axiomatic Design

Keywords: Axiomatic Design; Reliability Design; Complexity

1. Introduction

The information age is bringing unprecedented challenges to the development of products. On one hand, the product features are becoming more and more complex, and the product updating speed is faster and faster. On the other hand, the product quality and reliability need to meet the increasing demanding level. With the increasing complexity of products, and the functions and structures becoming more complex, the coupling between modules and the uncertainty to achieve the functionality within the system will be substantially increased. In this case, traditional reliability design and analysis methods are difficult to carry out, thus how to realize the reliability design requirements for the highly reliable product becomes an important bottleneck in the product development.

Axiomatic Design was presented by Massachusetts Institute of Technology (MIT) in the 1970s. It is a design method of decision-making for product design which provides a theoretical foundation based on logic and rational thought processes and tools, so that the designer may complete a product no longer depending on the personal experience and technical information, and he can determine the best design from many designs, so as to provide a good way to reduce the cost, and improve the quality and reliability [1]. Over the years, many scholars around the world carried out a lot of research works around Axiomatic Design theory, and tried to combine Axiomatic Design theory with reliability methods to solve the reliability design problems.

This paper reviews the associated concepts and research statuses of reliability design, Axiomatic Design and complexity theory, and discusses the relationships between them. On this basis, the domestic and foreign researches of reliability design method based on Axiomatic Design theory are analyzed. Finally, a kind of research thought about the reliability design on Axiomatic Design of complex system is proposed. The method can consider the ‘top-down’ design

Peer-review under responsibility of the scientific committee of The 10th International Conference on Axiomatic Design
doi:10.1016/j.procir.2016.07.027

features of complex system, and combine Axiomatic Design theory with the existing reliability design methods together. This provides an idea to solve the reliability design problem of highly reliable system in engineering.

2. Reliability Design Method

Reliability is a subject that struggles with the failure, and it focuses on the study to recognize failure reason and failure mechanism, thus to prevent or control the failure by using these failure rules. [2] The goal of reliability design is to meet the user's reliability needs. In the design process, various factors affecting the product reliability should be systematically considered, so as to carry out the analysis, evaluation, re-design on the product's candidate programs. For complex system, reliability is commonly characterized by the ability to maintain system function in the life cycle (or guarantee period, use life and economic life period, etc.). Reliability is unable to design itself and reliability design must be relied on other performance design or functional design, so as to design the reliability into the product.

According to the reliability requirements of the product, the common reliability methods consist of simplify design, redundancy design, fault-tolerant design, environmental protection design, thermal design and component selection and control, derating design, etc. [3]. These methods provide reliability design ideas and methods to meet the reliability requirements of the product from different angles, and play an important role in promoting the development of product design level.

However, with the increase of reliability and complexity of the high reliable products, the role of these reliability design methods becomes more and more limited. The overseas study found that the traditional reliability technologies emphasized on reliability work after the completion of the product building, which could only solve the problem of reliability of 20%. As the complexity increases, the design of the system architecture is more and more important. If we begin the reliability design in the conceptual design stage of the system architecture and product design, we can solve the problem of reliability of 80% [4]. Therefore, we must develop new reliability design methods on the new features of the system or the product.

3. Axiomatic Design Theory and Complexity Theory

3.1. Analysis on Axiomatic Design Theory

In 1970s, Nam P. Suh of Massachusetts Institute of Technology (MIT) proposed Axiomatic Design theory. Axiomatic Design is a design method based on domain and design axiom. It is not a special design, but it is the basic theory and method to study how to implement the correct design by using the design axiom.

There are two basic design axioms. The first axiom is the independence axiom, which means maintaining the independence of the functional requirements (FRs). Independence axiom refers to maintain independence of FRs, at the same time indicates the relationship of FRs and DPs. That is to say, the design project must meet each independent function demand, without affecting other functional requirements, which is implicated that DPs cannot be connected with other FRs. The second axiom is the information axiom, which means the information content of the design should be minimum. Information axiom refers to among those designs satisfying the independence axiom conditions, the design with the minimum amount of information is the best one. Because the information content is determined by the probability, this axiom also shows that the design with the highest probability of success is the best design. For the same design task, different designers may draw different design schemes, and it is also likely that these programs all meet the independence axiom, the design with the least information content is the best design during the evaluation. [1]

Axiomatic Design divides the design process into four domains: customer domain, functional domain, physical domain and process domain. The domain structure and the relationship between the domains are shown in Figure 1. The theory carries out analysis and induction through a large number of examples of successful design, abstracts the nature of the design process, expands the design in the 'top-down' design process from the high level of design abstraction concept to the low level of design details gradually. In each domain, the design problem is solved according to the shape of 'Z'. The design axioms and their reasoning theories make the originally design criterion developed from the experience even the intuition have a scientific basis, thus to provide a scientific basis and guiding principle for the design of the products. Axiomatic Design has been widely concerned in many academic and industrial areas. [1]

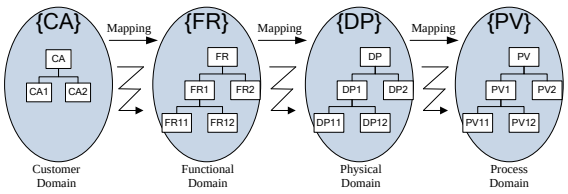

Fig. 1. Design mappings and domains

3.2. Analysis on Complexity Theory

The main effect of complexity on the development of the product is that the uncertainty to complete the desired function, and the uncertainty mainly means that the matching relationship is uncertain between the functional requirements and design results. From the point of view of whether or not the product range changing as the function of the time (static or dynamic), the complexity can be divided into time-independent complexity and time-dependent complexity.

Time-independent complexity can be divided into imaginary complexity and real complexity [5,6]. The so-called imaginary complexity refers to the increase of the product function and the complexity of the function, which leads to the difficulty of finding the reasonable design matrix. The typical situation is when lots of general modules are used to achieve a variety of functions, the corresponding relationship between the modules and the functions becoming very complex, the logic and behavior being completely in flexible configuration, and then what kind of configuration is optimal is a difficult