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Study on the collaborative design PN-PDDP model for the multi-component coupling rotor system based on Petri nets

Guoyuan Zhang[a,] *, Feng Ji[b], Weigang Zhao[b], Tuanjie Li[a]

[a] *School of Electromechanical Engineering, Xidian University, Xi'an 710071, China*
[b] *Xi'an Aerospace Propulsion Institute, China Aerospace Science and Technology Corporation (CASC) , Xi'an 710100, China*

* Corresponding author. Tel.: +86-029-8820-2470 ; fax: +86-029-8820-2470. *E-mail address:* gyzhang@xidian.edu.cn

Abstract

Based on the analysis of the characteristics for the design process in the complex multi-component coupling rotor system, and considering the fact that the multi-components co-design is demanded in the design process of the performance-driven target coupled rotor system, a PN-PDDP (Petri Network for Performance Driven Design Process) model based on the extended Petri nets is presented. The model defines the libraries of the performance and structure characteristics, the traces Token and firing rules. With the model, the flow process of the various coupled information flow is described, and the conflict resolution mechanism for the conflict information is developed. The model also offers guidance on the construction of the related database and design platform, which will provide the important design tools and implementation means for the design of the multi-component coupling turbopump rotor system in the liquid rocket engine.

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1. Introduction

The design process of a complex system or project is, in effect, a collaborative process, even involving teams or individuals across different places. This is especially true when the teams are made up of engineers across widely different fields. There are a certain number of researchers who have conducted research on collaborative design and platform for a complex system or product in certain field. For example, in the field of aerospace, the NASA of the United States has developed the CEE (Collaborative Engineering Environment) so as to promote the collaboration among design teams geographically apart. The key idea of the CEE is the collaborative multi-discipline design and the whole life cycle design. In this paper, a design method on high-performance high-speed turbopumps is studied. At present, the separate developments of varied technologies involved in high-speed turbopumps have set the stage for the integration design. For example, great achievements have been made in bearings, seal, and balance discs by our research teams [1-3], which was impossible in the past. Nonetheless, the design of a complex multi- component integrated system is extremely complicated, calling for the collaboration of researchers from different departments and fields. Therefore, this paper proposes the collaborative design PN-PDDP model for the multi-component coupling rotor system based on Petri nets with a view to facilitating fast and efficient design. There has been some development in applying the Petri nets theory and computer technology into system design, such as making judgments on information or monitoring information flow, the characteristics and strengths of which are obvious [4-6]. Specifically, Xiao ZJ et al. advanced the work-flow planning method based on colored Petri nets, in which the integration of static and dynamic local optimization was achieved via effective task grouping and stage dividing [4]. Zhang GB et al. conducted modeling for assembly reliability based on generalized stochastic Petri nets [5]. Zhang JL et al. presented

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a stochastic Petri nets support for exception handling flexible workflow modeling and performance analysis method [6].

Quite a number of researchers have also conducted research on the development of Petri nets-based long-distance cooperation system or product collaborative design system [7-13]. For example, Kuisak A advanced a Petri nets-based complex system design model and analysed its characteristics [7]. Karniel A et al. summarized the designing process of complex products, and spoke highly of the Petri nets-based design [8]. An and Li presented a formalized method of process control Petri nets for entire collaborative design process, which allowed variability in the design process and multi tasks to be executed simultaneously according to the different process definitions [9]. Ouertani M Z examined the knowledge flow in the product design process from the perspective of collaborative design [10]. Han et al. presented a multilevel Petri nets-based distributed collaborative research and design system design model for complex products, and conducted a project analysis on the distributed collaborative research and development system of new regional aircraft ARJ21[11]. He et al. presented a multi-level colored Petri nets to characterize collaborative design, and developed a data-driven workflow engine according to the characteristics of collaborative design [12].

The present study presents a PN-PDDP (Petri Network for Performance Driven Design Process) model based on the extended Petri nets so as to enhance design efficiency and quality after analyzing the design process of the performance-driven multi-component coupling rotor system in the liquid rocket engine.

2. Design process of the performance-driven multi-component coupling rotor system

2.1. Performance characteristics model and structure characteristics model of the multi-component coupling rotor system

The performance-driven product design theories point out that the key to product design is to guarantee performance, which should guide the whole design process. Performance characteristics indicators have controlled the whole design process [13]. Meanwhile, modern design stresses that knowledge is the essential resource in design activities, and that the design process is the process of transforming knowledge from the task space in the solution space, which results in the mapping of product performance characteristics onto structure characteristics. The product performance characteristics model is a hierarchical model, in which the high-level characteristics are abstract and general, the low-level characteristics are instantiation of high-level ones, and accordingly the former can realize the latter. Unlike the performance characteristics model, the product structure characteristics model is a high-level model based on the product assembly relationship, which is realized by low-level substructures via the assembly relationship.

In the initial stage, the product performance model obtained through user requirements analyses includes only component of product performance characteristics, and the abstract higher component of those characteristics has yet found its counter-component in the extant structure characteristics, and demands further decomposition into more specific performance characteristics. The process of working on and decomposing the product performance characteristics is termed the performance decomposition process, which aims at realizing high-level performances and obtains low-level performance activities via decomposition. The complete product performance characteristics model finally obtains as a result of the whole design activities.

The product structure characteristics model in the initial design stage can only meet component of initial product performance requirements such that it calls for improvement. During the design process, the designers would constantly improve the structure model in order that the improved structure model would further meet the product performance requirements, which is termed the structure design process. Building a product structure characteristics model is to establish a mapping relationship between the product structure characteristics and the performance characteristics models so as to present the whole performance characteristics needs. Fig.1 displays the performance characteristics and the structure characteristics models of the multi-component coupling rotor systems.

The performance decomposition process and the structure design process are not independent but interactive. This is because the former is based on the latter, and the precondition of the former is that the concrete structure is determined. With reference to the multi-component coupling rotor systems focused on in this paper, the performance characteristics model refers to the rotor supporting components and its dynamic performances. If the relevant components are not determined, the performance decomposition cannot proceed. On the other hand, once the rotor support bearing and coupling components are determined, the performance of rotating rotor system, supported by this kind of bearings, could be further decomposed into the load performances and dynamic performances.

2.2. Formalization of the design process

To build a PN-PDDP (Petri Network for Performance Driven Design Process) model based on the extended Petri nets, the following attempts have been made on formalization in line with the performance-driven design process theory.

Definition 1: The product performance characteristics model $[P]$ is to describe product performance characteristics as well as their interrelationships.

Definition 2: The product structure characteristics model $[D]$ is to describe product structure characteristics as well as their interrelationships.

Definition 3: Design activities is defined as the mapping process, in which the product performance characteristics model is mapped onto the product structure characteristics model under the guidance of the defined performance characteristics.

In this paper, design activities fall into two categories:

1) Performance decomposition activities are defined as the activities which operate on the product performance