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A systematic approach to coupling disposal of product family design (Part 2): case study

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Abstract

In this part of the work, we described the application of coupling disposal of product family design proposed in Part 1 on bridge crane. Firstly, axiomatic design theory was utilized as framework to analyse functional requirements and select suitable design parameters with "zigzagging" mode. Secondly, the trolley of bridge crane and its safety protection devices were considered as a real case to be analysed in detail. According to the relation between functional requirements and design parameters, axiomatic design matrix of bridge crane was built, and design structure matrix was constructed. Considering comprehensive correlation degree among design parameters including their functional relevance, connection relevance and physical relevance, we clustered and grouped design parameters into modules with less dependent degree in design structure matrix. Then coupling incidence matrix of product family design for the trolley is established, and it is discussed on the coupling inside modules and the coupling among design parameters with different modules. According to analysis on incidence influence degree, implementation sequence of modules is identified and corresponding decoupling method is proposed.

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Keywords: bridge crane; product family design; coupling analysis; decoupling; axiomatic design

1. Introduction

The bridge crane is a kind of important industrial production equipment, and widely used in industrial and mining enterprises, railway transportation and port *etc*. Its design process is complex and changes with work condition and loading characteristics. The bridge crane has many types, which is a typical customized product, and its variants are mainly determined by lifting capacity, operating speed, classification group, use conditions and so on. The change of each design factor can generate some new product variants, but they are often improved and modified based on existing machine types. The traditional design methods of bridge crane are generally suitable for small batch design modes with excessive reliance on experienced designers, and don't quickly respond to the needs of individual customers at low cost.

Product development based on a suitable platform has been the main tool for reducing complexity without sacrificing innovation. A well-designed product platform has been proven an effective strategy for product development to economically and efficiently create product families that provide sufficient product variety and market coverage [1]. Product family design is a difficult task - it involves all of the complexities of product design compounded by the challenges of coordinating the design of multiple products. Successful development of a platform and deployment of a product family require input from multiple disciplines [2]. Since there exists the relationship between modules within a given product family, it may induce the coupling of product family design and increase the difficulty of product design. However, most investigations have not addressed the problem of coupling for product family design [3]. The existing researches on coupling analysis are oriented to single product, and are mainly for design iterative sequence to achieve functional requirements (FRs). Xiao and Cheng [4] presented a systematic approach to decoupling of product family design based on AD and coupling incidence matrix.

In this paper, the trolley of the bridge crane is used to discuss coupling association between design parameters (DPs)

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in product family, and corresponding decoupling method based on axiomatic design and coupling incidence matrix is proposed.

The rest of the article is organized as follows. Section 2 discusses disposal strategy of the coupling in product family design. In section 3, a method of analysing and disposing coupled design for product family on bridge crane is proposed. Finally, the conclusions are remarked in section 4.

2. Disposal strategy of the coupling for bridge crane design

The basic purposes of bridge crane are hoisting, traversing in longitudinal and latitudinal direction with a certain speed, and other functional requirements. Taking the basic type of 20t crane as an example, its classification group is A7, span L is 19.5m, lifting height H is 12m, lifting speed v is 18m/min, trolley traversing speed v_t is 48 m/min, and crane traveling speed v_t is 72m/min, respectively.

AD offers a judgment criterion for successful design and improves design activities [5]. In this paper, independence axiom in AD is utilized to analyse functional requirements of bridge crane that are classified into basic functional requirements, expectable functional requirements as well as adjunctive functional requirements. And then functional requirements are mapped into design parameters. According to the relationship between FR and DP, and sensitivity and differences among design parameters, platform parameters are identified. This will weaken the coupling of product family design from strategy level of product family plan.

In AD, decomposition is realized by zigzagging methodology between functional domain and physical domain, and hierarchies for FRs and DPs are created in their respective domain. For bridge crane design, functional requirement of the highest-level (FR_0) is determined, representing the main requirement of the hierarchy, with the mapping of the corresponding design parameter (DP_0):

FR_0: Hoist, traverse in longitudinal and latitudinal direction.

DP_0: Bridge crane with electric double-beam-trolley.

After FR_0 and corresponding DP_0 were determined, the decomposition of the next level was done by using the AD zigzagging method, as shown in Fig. 1.

Based on designer's experiences, the mapping between FRs and DPs can be described with the following equation.

$$\begin{bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ FR_4 \\ FR_5 \\ FR_6 \end{bmatrix} = \begin{bmatrix} 1 & & & & & \\ & 1 & & & & \\ & & 1 & & & \\ 1 & 1 & 1 & 1 & & \\ 1 & 1 & 1 & 1 & 1 & \\ 1 & 1 & 1 & 1 & & 1 \end{bmatrix} \begin{bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ DP_4 \\ DP_5 \\ DP_6 \end{bmatrix} \quad (1)$$

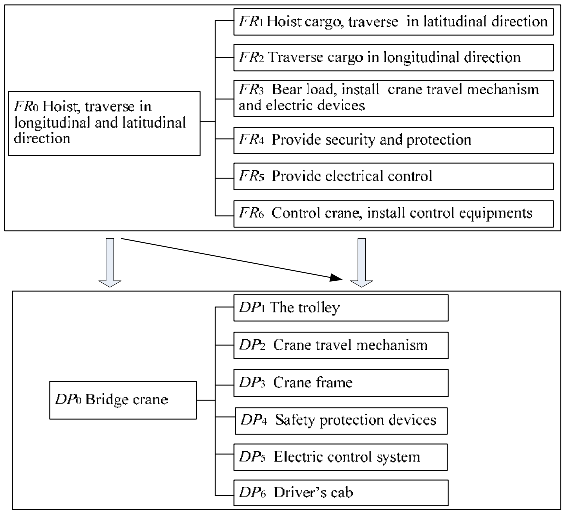

Fig. 1. Mapping and decomposition of functional requirements-design parameters of bridge crane.

From Eq.(1), we can see that there is no coupling among FRs and only exists unidirectional associations on the whole. This is a kind of decoupled design, and the independence of FRs can be guaranteed if and only if the DPs are determined in a proper sequence. FRs and DPs should be decomposed to the leaf-level until we create a hierarchy. Then, design parameters responding to basic functional requirements are identified, such as $FR_3 \rightarrow DP_3$. The basic structure of bridge frame is composed of double girder and end carriage. The section of girder and end carriage could be modified. The basic structure types of hoisting mechanism, trolley traverse mechanism and crane travel mechanism are lifting motor – brake - winder, trolley traverse motor - brake- trolley wheel group and crane travel motor - brake - crane wheel group, respectively. These basic structures are regarded as common parameters that satisfy basic functional requirements of bridge crane. Due to limited space and functional similarity, this paper only analyses the trolley and its safety protection devices.

For coupling analysis of product family, it is unnecessary to define the trolley and safety protection devices to the specific numerical values in the mapping process of FR-DP. These design parameters are not given with specification and type, as shown in table 1 and 2 such as motor, brake, reducer and so on. According to customer satisfaction, the FRs of bridge crane are divided into basic functional requirements, expectable functional requirements and adjunctive functional requirements. Each DP corresponds to one FR. DPs that reflect basic functional requirements for product family are defined as common parameters, and that reflect adjunctive functional requirements are defined as customization parameters. Then design matrix of the trolley based axiomatic design is established. Since design matrix can't capture the interactions among the design parameters in design process, it should be converted to design structure matrix (DSM), reference to literature [6]. DSM is a popular representative and analysis tool for system modeling, especially for purposes