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Procedia CIRP 60 (2017) 332 – 337

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27th CIRP Design 2017

Product Family Flexible Design Method based on Dynamic Requirements Uncertainty Analysis

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Abstract

Developing product families has been recognized as an efficient and effective means to realize sufficient product variety to satisfy a range of customer and support mass customization manufacturing. This paper presents a product family flexible design method based on dynamic requirements uncertainty analysis. The product family dynamic uncertain requirements analysis and forecasting techniques is researched in this paper, aims to improve the dynamic response ability of the product family to the change of the market demand in the future. Firstly, the multi-domain transmission mode of dynamic requirements was discussed and the product family flexible design model was proposed. Then the sensibility of design parameter to dynamic requirements was analyzed and the variation index of design parameter was calculated. As a result, the product platform of product family flexible design was constructed. A product family flexible design prototype system was also developed, and the application verification for flexible design of forging press product family was carried out to demonstrate the validity of the proposed method.

Peer-review under responsibility of the scientific committee of the 27th CIRP Design Conference

Keywords: Product Family; Flexible Design; Dynamic Requirements; Uncertainty analysis; Immune clonal algorithm;

A. INTRODUCTION

As the more effective method to meet the growing individual request, the technology of platform-based product development was the hot topic in the past few years, the product platform offer plenty of benefit: different products which come from the same platform can share a core set of common platform elements. As a result, company can reduce development time and costs, simplify system complexity and improve the ability of upgrade products. But the weakness of platform-based product development exposed gradually. Due to the product family members share too many common elements to highlight individuality. For that reason, the research on flexible product family design is worth. Compare with product platform, the flexible product platform consider the uncertainty factors includes the product development in the future. The flexible platform based on dynamic requirements uncertainty is the more effective method to meet problem of mass customization.

In the few years, scholars have done a lot of researches on the question of flexible platform and dynamic requirements uncertainty. Suh E S [1] proposed a flexible platform strategy by incorporating flexibility into product platforms, the design process generate multiple design alternatives by analysis demand uncertainty [2], and then filtered the profitable flexible component design with minimum cost and economic profitability, the proposed process was demonstrated in automotive application case. Q Ma [3] integrated the method of parametric design into flexible product platform, and presented a rapid design method base on flexible product platform by adjusting key parametric, the application on belt conveyor demonstrated this method fit the problem of product family design efficiently. Kangyun Shi [4] combined the advantages of the modular-based and the scale-base product platform design, analyzed the unknown uncertainties related to customer needs, find out the key design parameters, through mapping between

Peer-review under responsibility of the scientific committee of the 27th CIRP Design Conference
doi:10.1016/j.procir.2017.01.037

the parameters and the physical structure, the critical flexible elements were determined, and the flexible product platform was constructed by extracting the common and the flexible elements. Uncertainty was a concept appeared in the field of philosophy, statistics, economics, psychology and engineering science. Aim at the optimization problem of uncertain structures design, J Cheng [5]~[6] proposed a constrained interval optimization model firstly, Mechanical performance indices was described as the objective and constraint functions of the design vector and interval uncertain parameters in this model. An algorithm integrating radial basis function, interval analysis, and non-dominated sorting genetic algorithm (NSGA-II) was put forward to solve the optimization problem of uncertain structures design. Paper [7] believed uncertainty was composed by inner-uncertainty and outer-uncertainty. A large number of researches about dynamic uncertain requirements forecasting method were done in Paper [8] ~ [11].

Concept of flexible product platform was introduced to improve the ability of product family dynamic response to market changes. After discussed the multi-domain transmission mode of dynamic requirements. A two-stage multi-objective optimization based platform design methodology (MOPDM) is proposed. Finally, universal motor platform is designed by the process proposed in this paper. The result shows that the method this paper proposed is better than one-stage MOPDM.

B. The Mathematic Model of Dynamic Requirements Uncertainty

1) the multi-domain transmission mode of dynamic requirements

Product development process is described by four design-domains according to axiomatic design theory. There is different design variables in each domain, it can also be described custom needs, function requirements, design parameters and process variables. The neighboring domain can impact each by variable mapping. It can be seen from Fig.1, changes in customer's requirements can be mapped to the change of the function and structure of product. The dynamic needs lead to various products. It is a complex problem to balance the ability of evolution and development time. In conclusion, market uncertainty cause the structure's uncertainty.

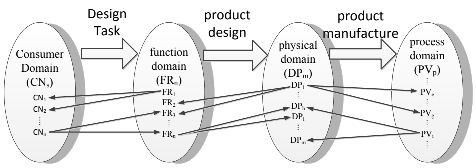

Fig 1. The multi-domain transmission mode

The mapping-relationship between consumer domain and function domain can described by the formula (1), A is named as request-function matrix.

$$\begin{Bmatrix} CN_1 \\ \vdots \\ \vdots \\ CN_s \end{Bmatrix} = |A| \begin{Bmatrix} FR_1 \\ \vdots \\ \vdots \\ FR_n \end{Bmatrix} \quad (1)$$

$$|A| = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1k} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2k} & \dots & r_{2n} \\ \vdots & \vdots & \dots & \vdots & \dots & \vdots \\ r_{m1} & r_{m2} & \dots & r_{mk} & \dots & r_{mn} \\ \vdots & \vdots & \dots & \vdots & \dots & \vdots \\ r_{s1} & r_{s2} & \dots & r_{sk} & \dots & r_{sn} \end{bmatrix} \quad (2)$$

Where, r_{ij} means the impact of the j-th function to i-th request. The bigger the r_{ij} is, the more important j-th function is to the i-th request: $0 < r_{ij} < 1$.

2) Analysis and Forecast of dynamic requirements Uncertainty

Customer requirements always is fuzzy and uncertain, the fuzzy mathematical theory [12] is applied in this paper to convert the uncertain requirements into numerical model. The demands intensity can be divided into six levels, and defined by the values in Table 1:

Table 1 Demand intensity and the corresponding value evaluation index

Intensity	strongest	stronger	common	weak	weaker	Irrelevant
Value	9	7	5	3	1	0

A matrix about the requirement important is established:

$$V = \begin{bmatrix} V_1 & V_2 & \cdots & V_{N-1} & V_N \end{bmatrix} \quad (3)$$

Where V means the demand intensity matrix, where V_1, V_2,V_N can only value from the table1.

Due to requirements can be mapped to function, the delphi technique [13] is applied to complete the requirement – function matrix：

$$B = V \begin{bmatrix} & A & B & \cdots & M & SUM \\ I & \xi_{IA} & \xi_{IB} & \cdots & \xi_{IM} & I_s \\ II & \xi_{IIA} & \xi_{IIB} & \cdots & \xi_{IIM} & II_s \\ \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\ N & \xi_{NA} & \xi_{NB} & \cdots & \xi_{NM} & N_S \\ SUM & A_k & B_k & \cdots & M_k & - \end{bmatrix} \quad (4)$$

Where, ξ_{NM} means degree the function M-th contributes to the requirement N -th, N_S means the importance of the N -th requirement among all the requirements, the higher N_S is, the more important this requirement is, M_k means the contribution to all the requirements. The higher M_k is, the more importance function is.

The importance higher than liminal value ϕ is regarded as important requirements, and contribution higher than liminal value φ is regarded as key functions. As result:

$$\begin{aligned} CN &= \begin{bmatrix} CN_3 & CN_7 & \cdots & CN_x \end{bmatrix} \\ FR &= \begin{bmatrix} FR_2 & FR_5 & \cdots & FR_Z \end{bmatrix} \end{aligned} \quad (5)$$