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Study on the Structure Decomposition of Steering Based on the Axiomatic Design

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Abstract. Taking the rack and nut type steering gear for an example, this paper analyzes the function demands of it according to the information needs of custom. On this basis, the relation of mapping between the function domain and structure domain is studied. Finally, the method of the structure decomposition for the rack and pinion steering gear is established by using the method of the configuration design and Axiomatic Design, which lays the foundation for the design of steering to achieve fast and effective.

Keywords: the rack and nut type steering gear; Axiomatic Design; structure decomposition

1. Introduction

The Steering is one of the key components of the automobile, which performance directly influences the maneuverability, stability and security of the whole vehicle. With enhancing of the customer requirements for the comfortableness, security and personalization of automobile driving environment，the design of the steering is becoming more and more difficult. Therefore, the difficulty of the study for steering is how to shortened the design cycle, reduced the cost, improve the design efficiency and rapidly design the product demanding the customer's needs. To take the rack and nut type steering gear for an example, the current reaching is mainly focusing on the design of the tooth form (gear shape), reliability and gear ratio etc. However, no research has been made about the methods of design effectively and fast for different requirements of the customer by analyzing the functional needs and the structure of steering.

Because it is different for customer to require the function and the structure of steering in practical engineering, the each order of the products is redesigned. The key of judgment the relations between design parameters and function rapidly is how to establish the design frame to solve the needs of the different users. Axiomatic design (AD) is a design theory to solve the question of development of the complex product, which can either forecast the design effect or explain the reasons choosing the design plan. Furthermore, the method of design quality assessment at an early stage is provided in this theory. In a word, it provides the theoretical basis for product design[1]. The aim is to achieve the rapid design of complex product. Based on analyzing the requirements information of user, requirements information is identified. Then the structure of steering can be analyzed in term of function using independent axioms of the axiomatic design theory. Thus helps to determine the design method accurately and achieve the product design rapidly and effectively.

2. Axiomatic Design

Based on Axiomatic design[2,3], the design of product is divided into four domains, that is , consumer domain, function domain, physical domain and process domain. The elements in the four domain are correlated with the Custom Needs（CNs）, Function Requires（FRs）, Design Parameters (DPs) and Process Variables（PVs）. As shown in Figure 1.

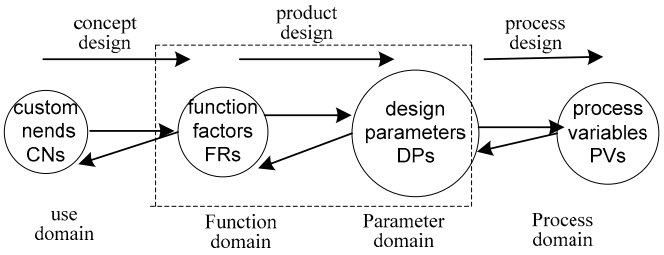


Fig.1 The Relation of Four Domains in Axiomatic Design

There are closely related between the neighbouring domains in the Axiomatic design. Accordingly, neither the question what to be solved nor the goal how to be achieved is put forward by the previous domain, and the plans how to realize are provided by the latter neighbouring domain. Each of the domains can be described hierarchically, and the goal of design is included in each layer. In fact, there is linearity mapping relation between the neighbouring domains of each layer. So the product design continuously solves the questions between the neighbouring domains. A series of functional requirements lie on each level of design objective. After design parameters are selected to guarantee the functional requirements, they can be decomposed into a series of sub- functional requirements, and such the process is repeated until design tasks are finished[4]. In the design process, the designer can evaluate the plan of design according to the Axiomatic design[5].

The basic principle of the Axiomatic design has two axioms. This paper mainly introduces axiom 1.

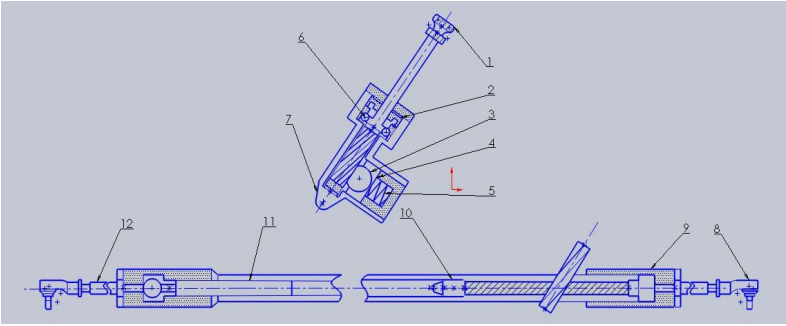
The axiom 1 (independent axiom): Maintain the independence of the function demands by choosing rational design parameters.

For example, there are corresponding relation between the function demand vector {FRs}of function domains and design parameter vector {DPs}in parameter domains, which is {FRs}=A{DPs}. A is a design matrix including the function requests and the design parameters, which describes the relation between FRs and DPs in the level of design. FRs is the minimal independence demand set of function requires, and DPs is the key parameter of design to realize the function demand of FR.

If A is the diagonal matrix, the design refers to uncoupled design. It indicates that the independence of the function demands is met through the design parameter. If A is the Triangular Matrix, the design refers to coupled design. In order to meet the independence requirements, the design parameters must be in accordance with an appropriate order. If A is the general real Matrix, the design refers to coupled design. The independence of functional requirements don't means that each part only meet the one function. Generally, it is the best design if a part can independently meet all the necessary requirements of function[6].

3. The Function Domain and the Parameter Domain of the Steering

The steering system is an important mechanism to change the driving direction, and maintains the vehicle stability in straight line. The performances directly influence the operational safety and driving. For the steering is a key part of the steering system, it helps to increase the torque of the steering wheel. That is to say, the steering can transmit the torque uploaded from the steering wheel into the larger torque through the steering gear ratio, which can be transferred to the steering rod. At last, the steering force is transferred to the wheels form the steering linkage. The aim is to achieve the change of vehicle direction. Now the rack and pinion steering gear is used in the car and the miniature and light truck widely. Its structure is shown in figure 2.



1.small gear 2. oil seal 3. rack 4. block 5. spring 6. bearing 7. steering shell

8. Steering Ball 9. dust cove 10. adjusting screw 11. pole 12 .steering knuckles

Fig. 2 The Rack and Nut Type Steering Gear

4. Structure Decomposition and Mapping of the Steering

The decomposition method of the Axiomatic design is adapted from abstraction to concretion and from top to bottom. The hierarchical structure of function domain based on the decomposition of demand information. Namely, the decomposition of demand information is an important gist for the hierarchical structure of function in the process of the conceptual design. The first layer is the general function mapping from general demand domain to general function domain. The sub-function is mapped by the sub-demand，and the function unit is mapped by demand unit. In a word, the product structure that meets the user needs is designed though mapping layer by layer.

Taking the design of the rack and pinion steering gear as an example, firstly, the general function and design parameters are determined from the layer relation of the main concepts in the information of user needs. Secondly, the hierarchical structure of function and design parameters are built using the zigzag mapping, as shown in Fig 3.

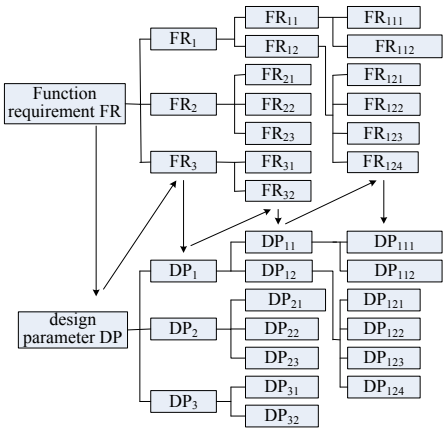


Fig.3 Decomposition of Function Requirement and Design Parameter for Steering

The first hierarchical structure decomposition. the basic function needs of the steering denoted by fr, which include the acceleration & deceleration torque of the steering mechanism (fr_1) , safety protection (fr_2) and assistant function(fr_3). correspondingly, the design parameters include the steering mechanism's parameters (dp_1), safety function (dp_2) and assistant structure (dp_3). the design matrix is as follows.

$$\begin{vmatrix} FR_1 \\ FR_2 \\ FR_3 \end{vmatrix} = \begin{vmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{vmatrix} \begin{vmatrix} DP_1 \\ DP_2 \\ DP_3 \end{vmatrix}$$

Where: X is a strong link, and 0 is a weak link or no contact.

Decomposition of the Second Hierarchical Structure. Deceleration and increased the torque is implemented by engaging the rack and pinion steering gear for the steering. From the function decomposition of the steering, it includes the deceleration (FR_{11}) and transfer torque (FR_{12}), safety protection and assistant functions. The functions of safety protection are decomposed into the Anti-collision (FR_{21}), locking (FR_{22}) and the shock absorber (FR_{23}) etc. Assistant functions consist of the lubrication (FR_{32}) and the anti-impurity（FR_{31}） preventing impurity from the pin hole and the rack, all of which are essential for the steering. Correspondingly, the design parameters include the decelerator (DP_{11}), Torque transfer device (DP_{12}), the structure of Anti-collision (DP_{21}), locking (DP_{22}), the structure of shock absorber (DP_{23}), anti-impurity (DP_{31}) and sealing structure.

$$\begin{vmatrix} FR_{11} \\ FR_{12} \end{vmatrix} = \begin{vmatrix} X & 0 \\ 0 & X \end{vmatrix} \begin{vmatrix} DP_{11} \\ DP_{12} \end{vmatrix} \qquad \begin{vmatrix} FR_{21} \\ FR_{22} \\ FR_{23} \end{vmatrix} = \begin{vmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{vmatrix} \begin{vmatrix} DP_{21} \\ DP_{22} \\ DP_{23} \end{vmatrix} \qquad \begin{vmatrix} FR_{31} \\ FR_{32} \end{vmatrix} = \begin{vmatrix} X & 0 \\ X & 0 \end{vmatrix} \begin{vmatrix} DP_{31} \\ DP_{32} \end{vmatrix}$$

Decomposition of the Third Hierarchical Structure. Deceleration function can be further decomposed into torque adjustment（FR_{111}）and meshing clearance adjustment（FR_{112}）, and transmission torque consist of inputting moment（FR_{121}）, export moment（FR_{122}）, connect function of torque transmission machinations （FR_{123}）and fixed function between the steering and bodywork. Correspondingly, the design parameters include the torque adjusting device (DP_{111}), rack adjustment device (DP_{112}), input device (DP_{121}), output device (DP_{122}), connection device (DP_{123}) and fixed device (DP_{124}).

$$\begin{vmatrix} FR_{111} \\ FR_{112} \end{vmatrix} = \begin{vmatrix} X & 0 \\ X & X \end{vmatrix} \begin{vmatrix} DP_{111} \\ DP_{112} \end{vmatrix} \qquad \begin{vmatrix} FR_{121} \\ FR_{122} \\ FR_{123} \\ FR_{124} \end{vmatrix} = \begin{vmatrix} X & 0 & 0 & 0 \\ 0 & X & 0 & 0 \\ 0 & 0 & X & 0 \\ 0 & 0 & 0 & X \end{vmatrix} \begin{vmatrix} DP_{121} \\ DP_{122} \\ DP_{123} \\ DP_{124} \end{vmatrix}$$

5. The Model of the Steering Design Process

The model of manufacturer of steering is a typical mass customization combined the customization and large-scale production, which can meet the demands all kinds.of customers .The rack and pinion steering gear is composed of gear, rack, spring, adjusting screw, lock nut, press block, dust cover, oil seal, bearing and shell etc. Those are decomposed the assembly, component and part in the design process. The method of configuration design can be used for the rack and pinion steering gear. The product functions are mapped to the product structures according to the principles of Axiomatic Design, and then the stability of the product design can be ensured. The design process model of steering is shown in figure 4.

The manufacturer of steering is a mass customization mode， and the configuration design is a key to achieve mass customization. Consequently, based on the configuration design and Axiomatic Design in the process of steering design, it is help to develop personalized product severing customer demands and to analyze the relationship between functional requirements and design parameter rapid.

According to the theory of Axiomatic Design, if there are more than one plans in the process of steering design, the evaluation is necessary through the Axiom 2 (information axiom) [7]. But this paper only analyzes the design process of the rack and pinion steering gear by Axiomatic Design, and the evaluation of multi design projects don't discuss.

6. Conclusion

In this paper, the relation of mapping between the function domain and structure domain, and then the method of decomposition for the rack and pinion steering gear is established based on the configuration design and Axiomatic Design. It lays the foundation for the design of steering to achieve fast and effective.

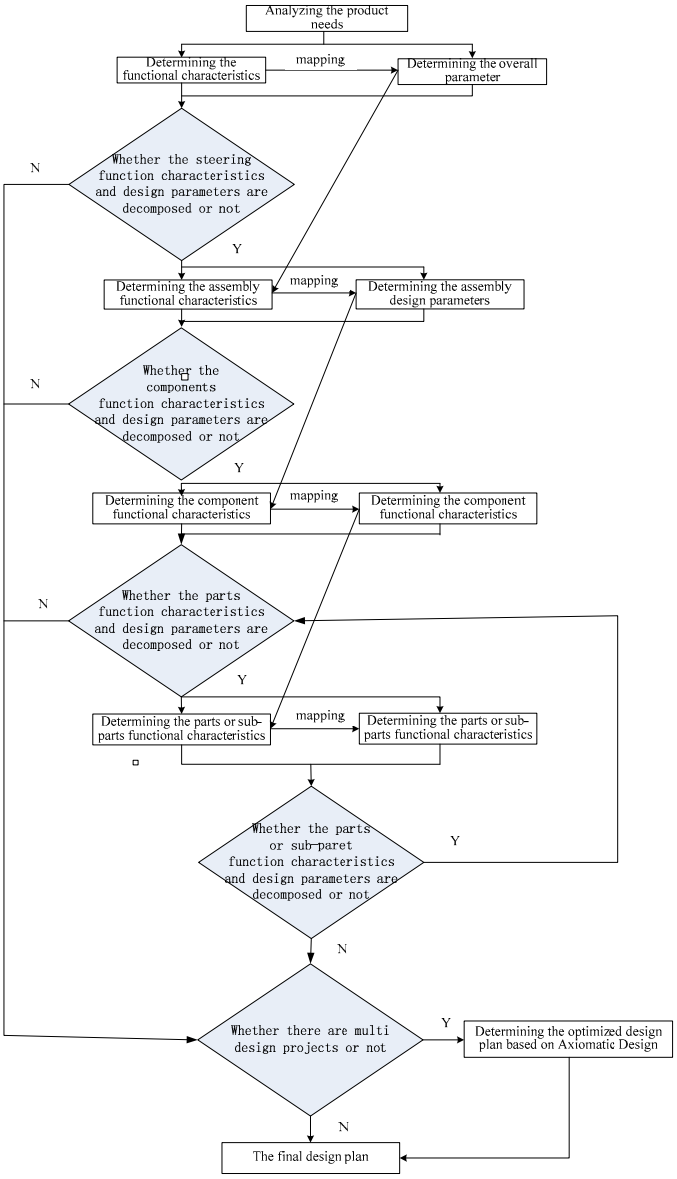


Fig.4 The Design Process Model of Steering

7. Acknowledgement

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