STUDY ON TOPOLOGY CONSTRAINT DESIGN UNDER COMPLEX MECHANICAL SYSTEM OF TOPOLOGICAL STRUCTURE

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ABSTRACT: Complex mechanical system is a complex, decomposable, and multi-targeted and constrained system. Multiple sub-systems are mutually independent, associated and restrained. Working processes of assembly line system are complex, which includes loading material, transmission, positioning and processing. Processing stations are mutual associated and restrained with non-linear relationship. Therefore, this thesis defines assembly line system as a complex mechanical system based on features of complex mechanical system. This study is focusing on complex mechanical system based on assembly line system. According to above theoretical basis of complex system and analytical method, resolution theory determined by features of complex mechanical system was combined with topological structure. Thus, topology constraints design of complex mechanical system with topological structure was put forwarded.

KEY WORDS: complex mechanical system; topological constraint design; subsystem.

1 INTRODUCTION

There were many uncertainties of the systematic design because sub-systems of complex mechanical system were mutual independent and associated, and association of sub-systems is a complex non-linear link. Strong or weak coupling between sub-systems makes design's objective function, constraint condition and design variable complicated [1~3]. How to design mechanical structure and how to coordinate and unify human, machine, design method, environment and raw material also show that mechanical system was complicated. Human, machine, design method, environment and raw material made up a more complicated system that involves multi-disciplinary field. Because of motion structure and process route, mechanical system will generate multi-objective task [4~5].

The reason that there were multi-targets of complex mechanical system is that single function needs to be resolved into multilevel objects to be realized.

Specific function can be realized through the realization of different level of purpose. Because decomposed multi-objective task was mutual restraint and contradictory, there were multi-constraint. Purposes of design of complex mechanical system were improved expression of objective function, constraint condition and design variable [6~8].

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Topological structure of computer networks refers to mutual connecting format of website's stations. In local area network, it refers to connecting format of file server, workstation and cable [9~10]. Topological structure of computer networks quoted the study method of topology to study the dot and line relationship that is irrelevant to size and shape. Computer and communication device on network were abstracted as dots, and transmission media was abstracted as a line. Geometric made up of dots and lines was regarded as topological structure on computer network. Topological structure is the first step to establish computer network and is the basis to realize networking protocol, which have a significant impact on performance of the network, and reliability and communication expense of the system [11~12]. Because resolution theory determined by features of complex mechanical system was combined with topological structure, topology constraints design of complex mechanical system with topological structure was put forwarded.

2 DESIGN PRINCIPLES OF TOPOLOGY CONSTRAINTS

Design principles of topology constraints includes: (1) System decomposition-elementary subsystems were divided according to resolution theory for hierarchical division of complex mechanical system. (2) Determine constraint quantity- according to mutual mapping relation between sub systems of hierarchical decomposition,

a certain subsystem is to be evaluated that whether it had an intersection with all other subsystems. If there were intersections, this subsystem was regarded as common factor quantity of the system, in other words, this subsystem was regarded as common constraint quantity. (3) Ergonomic design was made under the constraint of common constraint quantity. If there were only machinery decomposition, decomposition will be made according to function and process route. All the other factors that need to be evaluated were on basis of "human". From the perspective of human, factor quantity was evaluated to analyze the mapping relation among subsystems [13~15]. Several main principles of topology constraints were put forwarded based on the combination of complicated system's scientific theory, machine design and topology constraints design.

2.1 Human-centered

The design concept of topology constraints took "human" as a starting point and sought constraint quantity of design of complex mechanical system from the "point of human being". Determine constraint quantity to complete the product means design for human beings. "Human factor" had to be considered during the design. Characteristic of human need to be taken into consideration to guarantee controlling and operating systems were easy to recognize and information processing of the operator were to be limited as much as possible to avoid misoperation. Interaction design has to take function of human body into consideration to assure that information send by system can be receive and respond correctly. Those products adhere to people first and provide advantages to human as much as possible.

2.2 Reliability principle

Reliability is an important part of the machine design. Reliability of man-machine system refers to human reliability and machine reliability [39]. Human reliability includes self-factors' reliability and non-self-factors' reliability. Self-factors of human were caused by unreliable of misoperation. Misoperations can be effectively decreased by establishing operation standards. Non-self-factors were caused by environment that brought adverse effect to the body such as physical fatigue and mental fatigue. Then, there will be an accident.

Thus, environments have to be taken into consideration when designing. Machine reliability refers to unsafe of the equipment itself or incompatibility of ergonomic design. Thus, reliability demonstration and measure of man-machine harmony have to be done during the design.

2.3 Harmonization principle

Study objective of the man-machine engineering is to maximize the effect of the system through optimizing the combination of human, machine and environment. Thus, this research studied interconnects among human, machine and environment. Coordination of subsystems has to be taking into consideration when designing. Relation of human, machine and environment guaranteed their inter-coordination. For consideration of total systems and overall situations, optimal combination is to be found.

2.4 The principle of unity

Systematic mode of thinking was dealing with problems with holistic view and a view of connection. Thus, when designing, holistic view should be grasped and design objective should base on system point of view, after which human machine allocation should be made with the consideration of general coordination. This research studied from system point of view to local, and then from local to global. Thus, unity of local and global was ensured.

3 DESIGN PROCEDURE OF TOPOLOGY CONSTRAINT

Following aspects were included in the design procedure of topology constraint:

3.1 Confirm systematic items

Before the design, aim and task, used-objects, constraint and market research had to be identified. Aim and task was the key to determine the final solution as well as key to analyze systematically. Identify used-objects was to understand personnel's characteristic so as to take different person into consideration. Constraints include technologies and environments. Comprehensive analysis will be made to the greatest extend.

3.2 System analysis and planning

First, human, machine, raw material, design method and environment of mechanical system were to be analyzed by system analysis and planning. Thus, characteristic of tasks was identified and the mechanical system characteristic were generally understood. For aim and task, there were hierarchical decompositions for machinery system based on functions, processes and structures, and thus subsystems were mapped out. Topology

network was established according to system analysis and planning.

3.3 Identify constraint quantity

Through systematic analysis and planning, subsystems were identified. “Human factors” were seen as principal quantity and constraint quantity was measured through collection mapping relation. After identified constraint quantity, this unit was regarded as design basis. Other units’ design was based on this unit. After identified constraint subsystem, hierarchical division of machinery system was made again based on constraint subsystem. Relations among subsystems and unified factor quantity should be taking into consideration when dividing.

Identify mathematical model of constraint quantity:

Mathematical description was as follows : $\mathrm{S}=\{x_i, i=1,...,n\}$ is a systematic variable set; $H=\{x_1,...,x_j\}$ is sub-constraint set of the system.

$S_i=\{i=1,...,k\}$ is the subset of S other than H; If there were joints of these two subsets, common factor quantity was set as δ; thus, this equation can be concluded: $S=S_1\bigcup S_2\bigcup\cdots\bigcup S_k\bigcup H$

$S_i\bigcap S_j=\phi$ or δ; $i,j=1,...,k$ and $i\neq j$

But $H\bigcap S_i=\delta$; $i=1,...,k$

Objective function of the system is: $F=f(S_1,..S_k,H)$

3.4 Systematic man-machine function allocation

Man-machine allocation was made to planned subsystems. The main concerns of man-machine allocation were system costs, efficiency and reliability. According to characteristic of human and machine, reasonable human-machine allocation was made to obtain the optimum combination scheme of human-machine and optimize the system’s overall effectiveness, including mapping of human and overall system and mapping of human and cellular system. The principle of which was to benefit work of the human, relieve people’s burden and ensure good coordination of human and machine.

3.5 Ergonomic design

After determining of constraint subsystem, ergonomic design to machine was made according to topology network of constraint subsystem.

Basis unit (constraint subsystem) had to be designed first. Under the constraint subsystem, other units were to be designed.

Coordination of human and technology system and factors of subsystems have to be taken into consideration when designing. This design includes mechanical structure design about people’s size, modeling and color design of people’s mental, human-computer interactive design and safety design.

Overall structure of topology constraint design was shown as chart1:

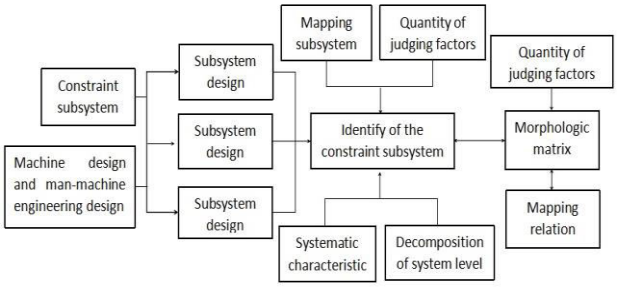

Figure 1 Overall structure of topology constraint design.

4 KEY POINTS OF TOPOLOGY CONSTRAINT DESIGN

When designing the man-machine systems, optimization scheme of general layout was to be achieved. When topology constraint design was used, several key points of design should be noticed:

4.1 Decomposition of system

Decomposition of system was the base of topology constraint design, which includes decomposition of system of complex mechanical system, basis decomposition of mechanical system, and decomposition of restrict of constraint quantity. Man-machine design of complicated mechanical system was started from human-machine-material-design method-environment. Basis decomposition of mechanical system is mainly about the hierarchical optimization that works according to its function and objects to server for dividing basis subsystems. Difficulty was the decomposition of restrict of machinery system’s constraint quantity. The main concern is influence of constraint quantity to other subsystems and the coordination of constraint quantity and another subsystem was sought. Systematic decomposition was performed in network topology models so as to measure the mapping relation among subsystem units.

4.2 Identify the constraint quantity

The basis of topology constraint design was multilevel decomposition of complicated machinery system and the core, identifying constraint quantity. For complex machinery system, system decomposition was non-hierarchical and most of their structures were hybrid hierarchy. Judgment of constraint subsystem relies on mathematical aggregation model. If there were direct relations among subsystems, it was assumed that there were overlaps between the two subsystems. δ denotes intersection coefficient, and then, intersection matrices were listed to be judged.

4.3 Man –machine function allocation

Basis of ergonomic design was full consideration of characteristic of man and machine. Optimum efficiency of system was achieved through inter-coordination of man and machine. Human body featured coordination and symmetry. The operation of the machine should be more easy and simple to handle, more consistency and more energy-saving. From general consideration, design of operation space should be combined with interactive design in order to maximize the efficiency of the system. When it comes to specific man-machine allocation, machinery property and limitation of human body, operations that corresponds to natural motion of human body to avoid physiological fatigue, differences of human body, and effectiveness and cost of machine replacement were to be taken into consideration.

4.4 Ergonomic design

Machine design belongs to practical operations of ergonomic design. “Human factors” had been included in machinery design of ergonomic design. Generally, machine design was divided into two parts of “hardware” design and “software” design. “Hardware” design is structural design of machine which is about human size in order to optimize the structure. “Software” design was about design of modeling, color and human-computer interface, function of human body, and psychological design to realize human’s psychological cognition.

5 PERFORMANCE TEST

There were no widely uses of the system in production workshop, thus effect of adjustment of production line were to be measured by simulation. Daily output of operators would be simulated first. Apparently, daily outputs of the operators were changing with the time. As a green hand, there would be a low daily output. With the rise of proficiency degree, daily output would be increased, which would stable at a certain number and there were no limitless multiplications.

A fragment function was used as following to simulate the change of daily output of an operator with the time.

$$Q(d)=\begin{cases}100+kd+rand(-20,60), 1\le d\le a\\ 600+rand(-20,60), d>a\end{cases} \qquad k>1 \qquad (1)$$

In this function, d denotes working time, which was number of days of an operator counting from the day of first operation to present. Q denotes the output in the dth days. k denotes scale factor. a denotes the time that efficiency of the operator was about to stabilize. r $rand(-20,60)$ was a random function, and k equals to 50 and a equals to 10. Assume that relation of operator’s daily output and time fits equation (1), thus it can be concluded from the results showed in figure 2 that uploading time of sewing equipment’s parameters was increasing with the increasing number of sewing equipment in manufacturing shop. Topology constraint design of production line can improve the practical production line effectively.

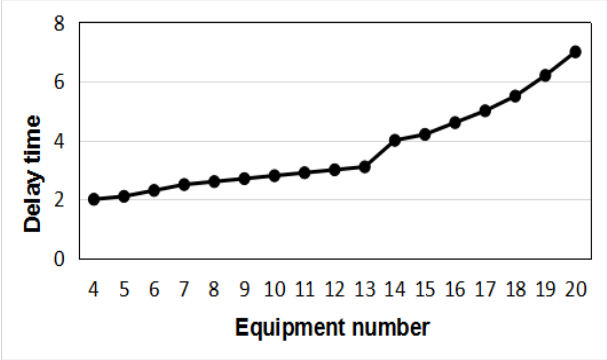

Figure 2 Relation of uploading time of sewing equipment parameters and numbers of sewing equipment in manufacturing shop

6 CONCLUSIONS

This thesis studied scientific thinking and basic theory of complex system, and thinking method of which was promoted to complicated machinery system. And characteristics of complicated mechanical system were analyzed. Constraint (basis) quantity of complex mechanical system was to be judged from the view of “human” by combining decomposition theory of system, topology structure and mapping relation of subsystem. Man-machine systems design method used in complex machinery system was put forwarded, in other words, topology constraint design. Design method, mathematical model, design

procedure and key points of design of this method were elaborated.

Design verification testing of packaging production line proved that this method was practicable. Using this method, designers can identify the design basis and constraint quantity of complex machinery system, and the relation of every parts were defined. However, as for general application, this method had to be improved.

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