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Axiomatic Design Approach for a Reactor Head Structure Assembly

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has been developing the integral reactor. The reactor head structure assembly (RHSA) is the structure installed over the reactor cover. Due to the characteristics of an integral reactor, there are many instrument cables and power cables coming out from the reactor cover and main components. The RHSA provides an interface location to connect these cables from Architecture Engineer (AE) and System Designer (SD). It also prevents a pipe whip and it prohibits instruments from becoming missiles. In this research, the axiomatic design approach for the RHSA is performed.

2. Axiomatic Design

The axiomatic design approach proposed by N.P. Suh consists of the Independence Axiom and the Information Axiom. The Independence Axiom assists a designer in generating good design alternatives by considering the relationships between the functions and the physical product by using a hierarchical mapping procedure. The Information Axiom, which is related to the probability of achieving the given functional requirements, can be used as a criterion for the selection of the best solution among the proposed alternatives during the conceptual or preliminary design stage.

In the axiomatic design, we must determine the design's objectives by defining them in terms of specific requirements, which are called functional requirements (FRs). Then, to satisfy these functional requirements, a physical embodiment characterized in terms of design parameters (DPs) must be created. The design process involves relating these FRs of the functional domain to the DPs of the physical domain. A design matrix is utilized to express the relationship between the FRs and the DPs. There are three types of design matrix shown in Eqs. (1)~(3) where "X" means a dependency between a FR and a DP and "O" means no dependency.

Coupled design

$$\begin{Bmatrix} FR1 \\ FR2 \end{Bmatrix} = \begin{Bmatrix} X & X \\ X & X \end{Bmatrix} \begin{Bmatrix} DP1 \\ DP2 \end{Bmatrix} \quad (1)$$

Decoupled design

$$\begin{Bmatrix} FR1 \\ FR2 \end{Bmatrix} = \begin{Bmatrix} X & O \\ X & X \end{Bmatrix} \begin{Bmatrix} DP1 \\ DP2 \end{Bmatrix} \quad (2)$$

Uncoupled design

$$\begin{Bmatrix} FR1 \\ FR2 \end{Bmatrix} = \begin{Bmatrix} X & O \\ O & X \end{Bmatrix} \begin{Bmatrix} DP1 \\ DP2 \end{Bmatrix} \quad (3)$$

In a coupled design, a change in FR1 cannot be accomplished by simply changing DP1, since this will also affect FR2. Such a design clearly violates the Independence Axiom. To satisfy all of FRs, DPs are determined by trial and error. Moreover, it is not guaranteed.

In a decoupled design, if you had changed DP2 first to set FR2, and then DP1 to set the value of FR1, the value of FR2 would have changed while changing DP1. If we vary DP1 first, then the value of FR1 can be set. Although it also affects FR2, we can then change DP2 to set the value of FR2 without affecting FR1.

In an uncoupled design, the independence of FRs is assured when each DP is changed. That is, each FR can be satisfied by simply changing a corresponding DP. This satisfies the Independence Axiom.

A coupled design could become a decoupled design by re-determining the FRs and the corresponding DPs.

3. Axiomatic Design of the RHSA

3.1 Problem Definition and Design Matrix Definition

The design matrix for RHSA is shown in Eq. (4). The design matrix shows that the design of the RHSA is an uncoupled design.

$$\begin{Bmatrix} \text{FR1: Provide interface location for cables} \\ \text{FR2: Prevent pipe whip} \\ \text{FR3: Prohibit instruments from becoming missiles} \\ \text{FR4: Restrain CEDMs' horizontal motion (option)} \end{Bmatrix} = \begin{bmatrix} X & O & O & O \\ O & X & O & O \\ O & O & X & O \\ O & O & O & X \end{bmatrix} \begin{Bmatrix} \text{DP1: Reactor disconnect panel} \\ \text{DP2: Pipe whip restraints} \\ \text{DP3: Protection structure} \\ \text{DP4: CEDMs restraints} \end{Bmatrix} \quad (4)$$

The RHSA should be designed to be removable for a refueling schedule. This is defined as a constraint.

For FR1 in Eq. (4), a lower level decomposition is needed. Since the definition of lower problems is affected by the decisions made at a higher level, a decomposition of the design problem requires a zigzagging process between the functional and physical domains. This zigzagging process will be employed in the conceptual design of a reactor disconnect panel (RDP). The design matrix for a RDP can be established in Eq. (5). Based on Eq. (5), it is recognized that DP11, DP12, DP13, and DP14 should be determined in sequence.

$$\begin{Bmatrix} \text{FR11: Minimize interface with other components} \\ \text{FR12: Minimize interface between cables} \\ \text{FR13: Stick connectors to RDP firmly} \\ \text{FR14: Maintain structural integrity} \end{Bmatrix} = \begin{bmatrix} X & O & O & O \\ x & X & O & O \\ O & O & X & O \\ O & X & x & X \end{bmatrix} \begin{Bmatrix} \text{DP11: RDP's q'ty, location, arrangement} \\ \text{DP12: Layout of connector holes} \\ \text{DP13: Connector fixing mechanism} \\ \text{DP14: RDP thickness, reinforcement} \end{Bmatrix} \quad (5)$$

3.2 RDP's quantity, location, and arrangement (DP11)

Two types of RDP are designed such as RDP for power cables and instrument cables. The installation location of RDP should be the upper area of the reactor vessel assembly (RVA). It is impossible to install RDP in the lower or middle area of RVA since there exist an internal shield tank (IST) and steam generator inlet/outlet nozzles.

3.3 Layout of the connector holes (DP12)

The final layout of the connector holes to satisfy FR12 is shown in Fig. 1. The hole location for a cable from an annular cover and the hole location for a cable from a central cover is designed to be separately located in RDP to minimize an interface between cables. The cables from similar instruments are put together in RDP, which helps reduce the human error probabilities during an installation.

3.4 Connector fixing mechanism (DP13)

For each connector to be fixed in the corresponding holes on RDP, it is determined to utilize four screws. And the integrity of screw is evaluated by calculating the shear stress, when the design load is applied to the connector.

3.5 RDP thickness, reinforcement (DP14)

When all the connectors and cables are installed in RDP and the design load is applied, the thickness of RDP and the ligaments' size between the holes mainly contribute the structural integrity. It is represented by the fact that the FR14 is affected by DP12 and DP14 in Eq. (5). A reinforced structure could be possible to satisfy FR14. Consequently, the parameter study by using a finite element analysis makes it possible to determine the proper size of the thickness and ligament without a reinforcement.

3.6 Pipe whip restraint, Protection structure, CEDMs restraints (DP2, DP3, DP4)

For the pipe whip restraints to satisfy FR2, pipe type restraints are established. For the protection of a structure to satisfy FR3, a bottom plate is designed. For the CEDM restraint to satisfy FR4, a top plate with holes for CEDMs is designed. The RHSA with all the designed components is shown in Fig. 2. For the constraint of a removablity, fixing bolts are utilized.

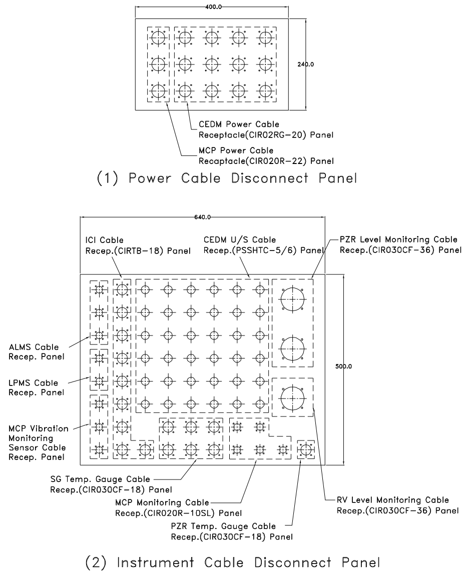

Fig. 1 Connector arrangement in RDP

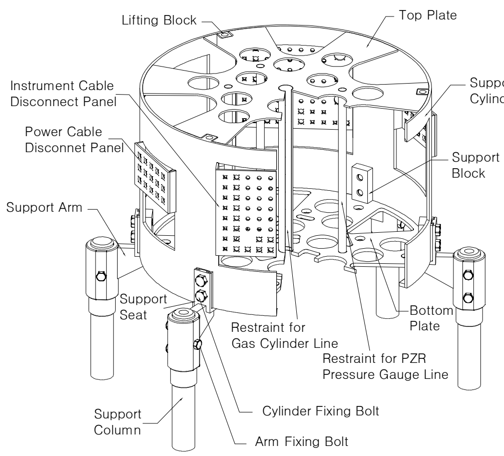

Fig. 2 Reactor Head Structure Assembly

4. Conclusion

The choice, design, and combination of every component in the RHSA are performed based on the axiomatic design approach. The FRs for the RHSA are defined, and the DPs to satisfy the FRs are determined in sequence. For a lower level decomposition, the zigzagging process is employed.

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REFERENCES

[1] N.P. Suh, 2001, *Axiomatic Design*, Oxford University Press, New York.