Model Based Design Adjustment Technique for System Design

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1. Introduction

Systems engineering is a systematic method for developing large-scale, complex systems. The method involves clarifying requirements based on the purpose and background of the system and proceeds with design while integrating multiple specialized fields (1). Systems engineering includes model-based systems engineering (MBSE), which is performed using models (2).

The development of systems and devices in MBSE also requires adjustment in detailed design to meet the system requirements. In many cases, the adjustment is performed using the results of detailed design utilizing calculation formulas that convert 1D/3D-CAE models and know-how into explicit knowledge in Excel *1.

With the aim of facilitating adjustment in system design, this paper defines a modeling method that specifies the dependencies between designs in different fields such as mechanical, structural, electrical, electronic, and software when constructing a system model using MBSE, and a method for linking the system model with the detailed design results of the 1D/3D-CAE model used in each design. It also describes the results of confirming the feasibility of analyzing the impact of each design result on the entire system using the defined method.

2. Method Design

2.1 Method overview

Systems engineering is a method of proceeding with the detailed design of the target system by examining the entire lifecycle of the system to be designed (development, manufacturing, transportation, installation, operation, maintenance, disposal, etc.), and by clarifying roles from the perspective of interactions with surrounding systems, stakeholders, environmental conditions, etc. (2) This makes it possible to reduce omissions in examining the functions to be provided by the system, thereby reducing rework from the post-process.

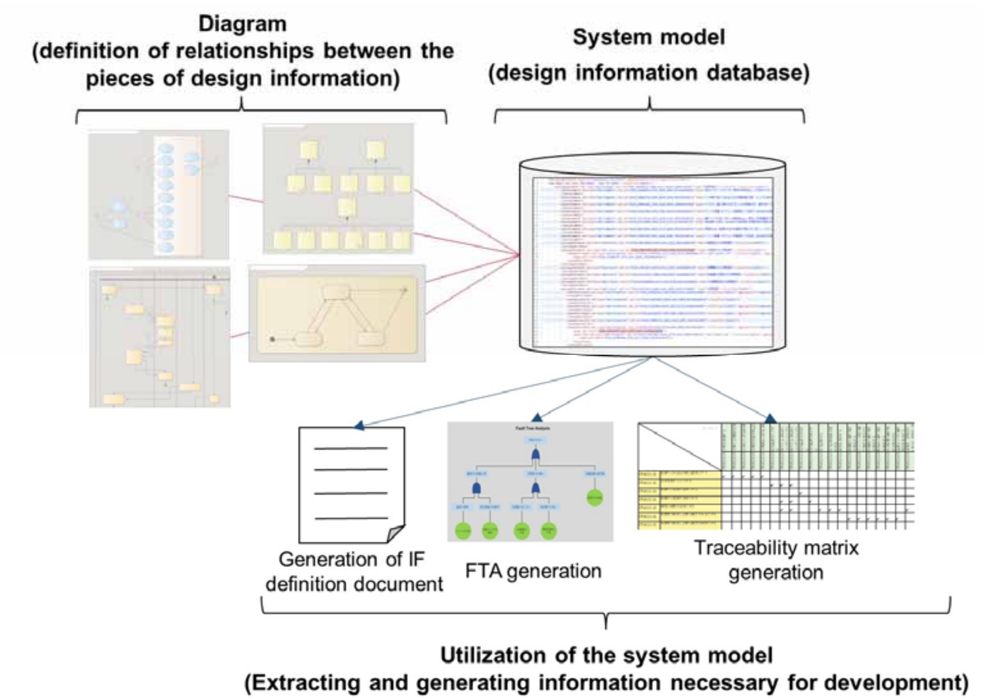

Fig. 1 System model and its utilization in MBSE

[1] Excel is a registered trademark of Microsoft Corp.

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In systems engineering, an enormous amount of information must be handled, so the design work should not be managed manually using documents, but should be implemented in a format that can be managed as digital data. This is used to create a database of design information so that the necessary information can be searched, and consistency can be checked using a computer. This database of system design information is the system model in MBSE which extracts the information necessary for proceeding with the design from the database and generates the format required for making design decisions, thereby promoting efficient, effective development [(2)].

The system model can be created by using various diagrams (Block Definition Diagram, Requirement Diagram, Parametric Diagram, etc.) based on notation such as SysML[(3)] *[2] in the MBSE tools to create relationships between the pieces of design information (Fig. 1).

In addition to the system model, models used in development include detailed design models by 1D/3D-CAE used in detailed design. The models are simulation models for optimization in each design field (mechanical, structural, electrical, electronic, software, etc.), and by adjusting the design results using the detailed design models, specifications that satisfy system requirements are derived. When making adjustments between detailed designs, design elements with dependencies that affect other designs are adjusted, but it takes time and causes omissions in examination because the adjustments are based on the tacit knowledge of each designer.

For this reason, a mechanism is created to extract the dependencies between detailed designs from the system model, which holds information about the entire system design, and to link the results of the detailed design models. As shown in Fig. 2, this makes it possible to visualize the impact of detailed design results on the entire system, thereby facilitating adjustment.

In order to realize this mechanism, definitions are made for a system model construction method that can specify dependencies between designs, a method of extracting the dependencies from the system model, and a linkage method that calculates the impact by passing the dependency information to detailed design models.

2.2 Definition of the system model

Some of the design elements (control cycle, component rating, power consumption, etc.) in each design field affect other design fields. For example, when designing an air conditioner, if the control cycle is changed to lower the fan speed to reduce power consumption, an impact event may propagate in which a change in heat dissipation causes a change in the performance value of the cooling and heating capacity in the design of the refrigerant circuit.

In order to be able to extract the propagation of impact across designs from the system model, the diagrams described in Section 2.1 are used to define relationships between the pieces of design information.

This method uses SysML Block Definition Diagrams and Parametric Diagrams to define the dependencies between the design elements of various designs and the target performance. In addition, performance targets, which are system requirements, are defined in SysML requirement diagrams. Figure 3 shows an example of relationships between the Requirement Diagram, Block Definition Diagram, and Parametric Diagram for an air conditioner. In this paper, Sparx Systems' Enterprise Architect is used as MBSE tools.

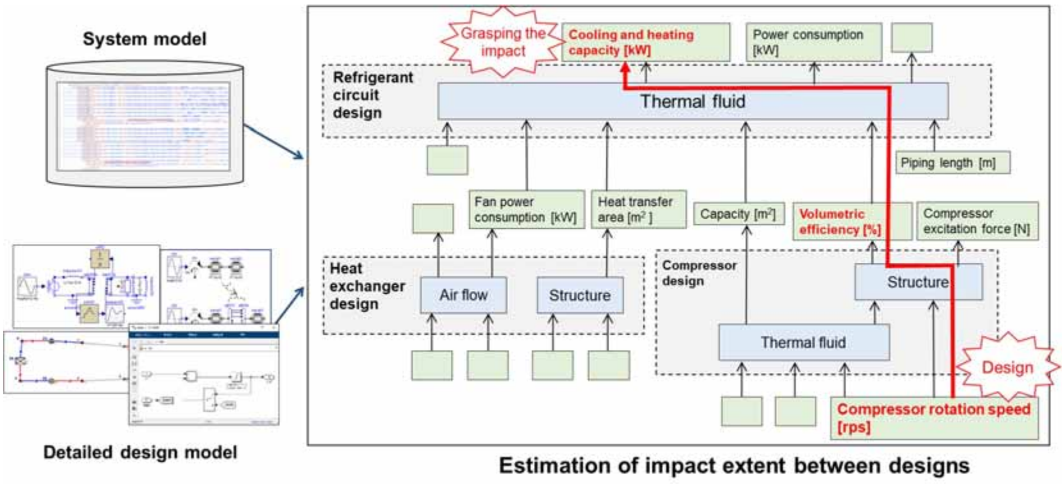

Fig. 2 Overview of adjustment facilitation method using system model

2 SysML is a registered trademark of Object Management Group, Inc.

2.3 Analysis of the system model

The system model shown in Section 2.2 is expressed as a SysML diagram, but as described in Section 2.1, it is actually a database of design information. The diagram shown in Fig. 3 is created using notation such as SysML, and the necessary pieces of information are distributed over multiple diagrams. When trying to use diagrams for development, all developers must be familiar with the notation and be able to understand diagrams without any discrepancies to find the necessary pieces of information from multiple diagrams. Therefore, it will be difficult for the people involved in development to use the diagrams as they are.

Many MBSE tools hold the details of each element defined on the diagrams and information about relationships with related elements in the format of eXtensible Markup Language (XML). By constructing a mechanism for extracting the necessary pieces of information from the contents of the diagrams expressed in XML, it becomes possible to make extensive use of the system model in the development process.

Here, to be able to extract the necessary pieces of information from XML, it is necessary to define relationships between the pieces of information defined in multiple diagrams. Considering the example of an air conditioner, if relationships between the pieces of information are not defined, it is not possible to trace on a computer that the target cooling capacity defined in the Requirement Diagram will be the performance target value of the refrigerant circuit design defined in the Parametric Diagram. As a requirement for the system model that enables tracing on a computer, it is essential to relate the pieces of information in the diagrams to each other.

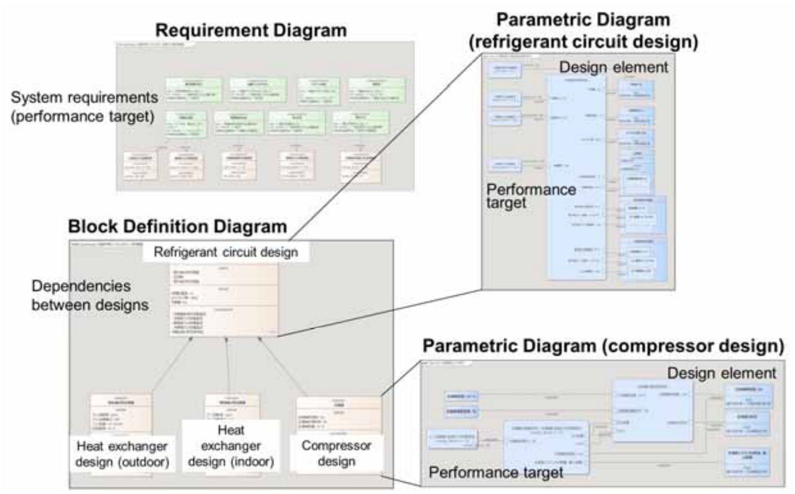

Fig. 3 Contents of system model

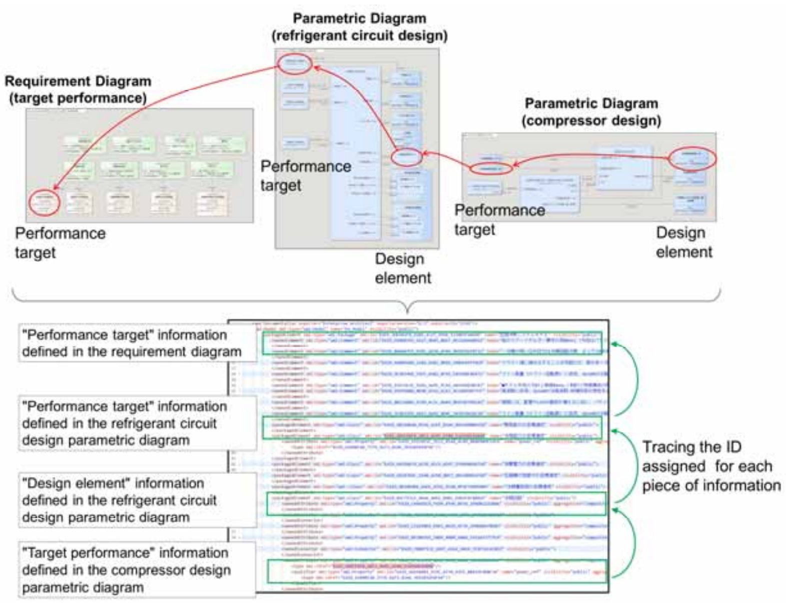

Fig. 4 Analysis of system model

Figure 4 shows that relationships between the pieces of information in the diagrams shown in Fig. 3 are defined, and the relationships can be traced on XML. The performance targets defined in the Requirement Diagram are used as the performance targets in the Parametric Diagrams, and the Parametric Diagrams relate each design element to each performance target. Also, a performance target shown in one Parametric Diagram is related to a design element in another Parametric Diagram. Looking at the relationships in terms of the XML structure, a unique ID is assigned to each piece of information, and the ID of each related piece of information is defined. This makes it possible to trace each related piece of information by referring to the ID, and to extract the relationship between the design element of one design and the performance target of another design. In this way, the pieces of information in the diagrams are related with each other, thereby enabling computer processing to extract desired information from XML.

2.4 Linkage method with detailed design model

The method described in Section 2.3 enables the extent of design impact to be traced from the system model. On the other hand, to estimate the impact quantitatively, it is necessary to link with the detailed design simulation models.

There are two methods for linking with these models: a method that links MBSE tools and simulation tools[4], and a method that converts the execution results of models for detailed design into approximate formulas to give the design values to the approximate formulas, and returns the results to the system model.

This paper defines the latter linkage method. This method takes a lot of time and effort to create approximate formulas, and it is less accurate than the method of linking with simulation tools. However, Mitsubishi Electric's products are diverse, and the simulation tools used for each business domain are different, and our own in-house tools and Excel calculation formulas are often used. Therefore, we have decided to use this method, which is easy to link with various tools. Figure 5 shows the linkage method between the system model and detailed design models according to this method.

As shown in Fig. 4, the design element and the performance value related to the design element are extracted from XML of the system model. The quantitative impact of the performance value when the value of the design element is determined is then calculated from the approximate formula of the relationship between the design element and the performance value. If the performance value for which the impact is calculated is a design element of another design, the performance value with further impact is extracted from XML and the magnitude of the impact is calculated from the approximate formula. By repeating this process it is possible to express the extent and magnitude of the impact that propagates when the value of a certain design element is determined.

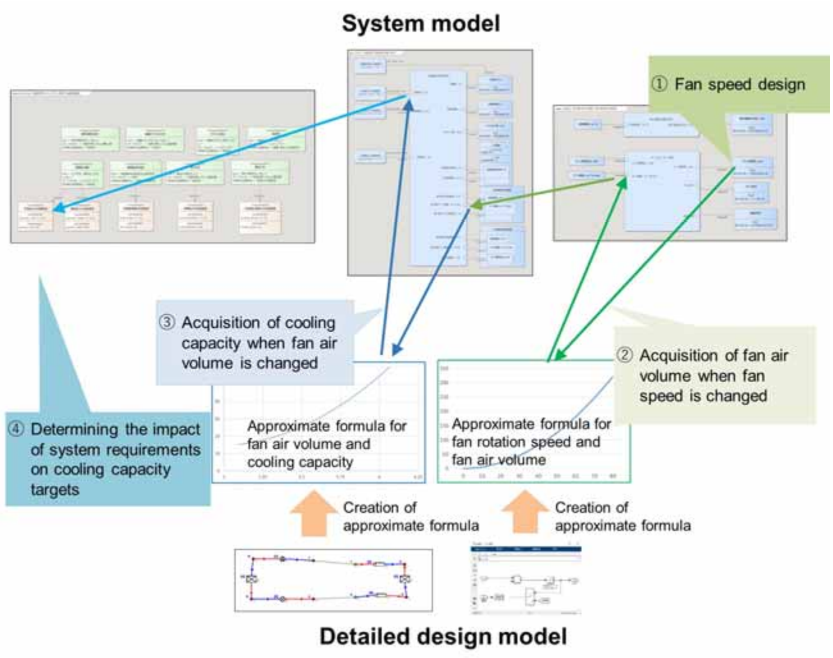

Fig. 5 Linkage method between system model and detailed design model

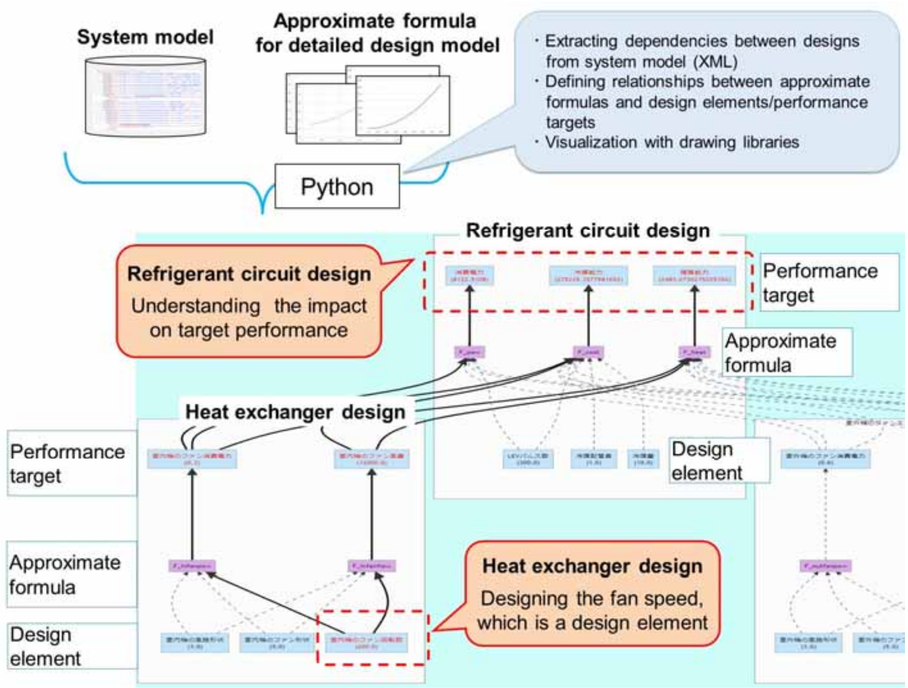

Fig. 6 Prototype of impact analysis across design

In order for this method to be widely used in actual development, the information extracted from the system model must be in a format that is easy for each designer in charge to understand. In examining the format, we aimed to make it possible to use the method without understanding special notation, to give an overview of the relationships between the designs of the entire system, and to easily understand the extent of the impact of changes.

To meet this goal, a prototype of this method was created using Python *3, which has a complete set of XML parsing and drawing libraries. Figure 6 shows the results of the prototype. By inputting the results of each design into the design elements by GUI (Graphical User Interface) operation, we have confirmed that the extent of the impact on the entire design is indicated by an emphasized line and the magnitude of the impact can be quantitatively indicated.

This prototype uses a format that enables intuitive understanding of the impact of design results using natural language and block diagrams. We believe that all developers will be able to grasp the impact of their own design content, and that it will be possible to easily adjust the system design.

3. Conclusion

By linking the system model that defines relationships between designs to the detailed design models, we have designed a method that enables anyone involved in development to easily perform an impact analysis across design fields. We have confirmed the possibility of using the prototype for development.

In future actual development, we will apply this method to cases where there are problems in adjustment between design fields and show that development can be made more efficient.

References

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[3] Python is a registered trademark of the Python Software Foundation.