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Integrated Design Method and Experimental Study for the Safety Performance Analysis of Nuclear Power Valve

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Abstract

Finite element analysis is the most common and effective design and research method used in nuclear power valve products. Due to the high security, shape complexity of valve cavity and the nonlinear of joint surface at sealing position, it is important to establish the finite element model quickly and accurately that could meet engineering accuracy and calculation condition that need urgently solved. In order to master the performances and rules in modeling process, the finite element analysis modeling common method for assembly and key components facing the safety performances analysis for nuclear power valve is deeply studied. On this basis, a new method on simplifying FEA model efficiently is proposed. The integrated platform could be constructed combined with the modeling method, the simplified model and the analysis process reuse method, which integrates design, simulation, and optimization of nuclear power valves together supporting heterogeneous model transfer. The validity of the analysis method above is verified by the valve strength and sealing tests, which is of certain guiding significance for other class of nuclear power valves.

***Keywords**: nuclear power valve; reuse process; multi-physics analysis; collaborative design*

1. Introduction

It is generally known that power station valves are important guarantee for the entire power plant to stabilize operation, power station valves control and regulate the flow and pressure of the medium inside the tubes to ensure power plant equipments normal and safe working. As the progress of nuclear power industry, power valve products are in the period of rapid development, and the requirements of high performance, low cost and short cycle are put forward to the design of nuclear power valves, so advanced digital design methods and integrated design system provide technical support in urgent need[1-4]. Especially under leakage of nuclear power station in Japan, there is important realistic significance to improve design ability of nuclear power valves and product performance. But at present, there exist a universal phenomenon of low efficiency and high processing cost during the valve manufacture process in domestic nuclear power valve business. And in the numerical calculation and analysis of nuclear power valve design, some of valve bodies are the main stressed components, which often embody in the irregular and relatively complex geometry, the complex work environment, and the impact damage of valve cavity under the working medium in different flow velocity, temperature, and chemical properties[5-7]. Due to the lack of the integrated design method, the rapid

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design method of power station valves exists some shortages, and it is not suitable for the current fast response design requirements of nuclear valves. Hence, it has become the key factor in improving the designing quality for the safety performance and shortening the research cycle of power station valves [1-3]. Therefore, developing the rapid design method for safety performance of the power station valves has important theoretical significance and practical value.

2. Key Techniques for FEA of Power Station Valves

2.1. Rapid Simplification of Valve Bodies CAD Model

According to different characteristic analysis of complex valve bodies structure, there are some questions emerging such as miscellaneous process of model simplification, low efficiency in simulation analysis and difficult reuse in reduction rule. So a new method, which combines with intelligence and fuzzy simplified determination method, can be adopted in order to simplify the CAD model efficiently for different characteristic analysis.

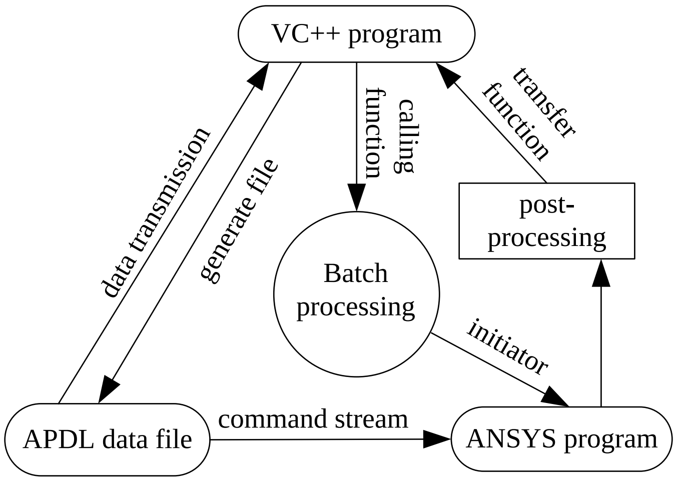

Figure 1. Schematic of VC++ Integrate ANSYS

Rapid modeling for the components of the valves and automatic assembly of the whole machine are realized by UG and ANSYS secondary development. Figure 1 illustrates the schematic of VC++ integrate ANSYS. The model simplification process of digital design is constructed to satisfy the need of the safety performance simulation analysis of nuclear power valve products, as illustrated in Figure 2. In the intelligent simplified interface, the batten of "structure analysis" can be selected according to the structure design needed. In order to avoid the simplified models are unrecoverable, the function of "suppression characteristics of simplified method" can be used to simplify the model.

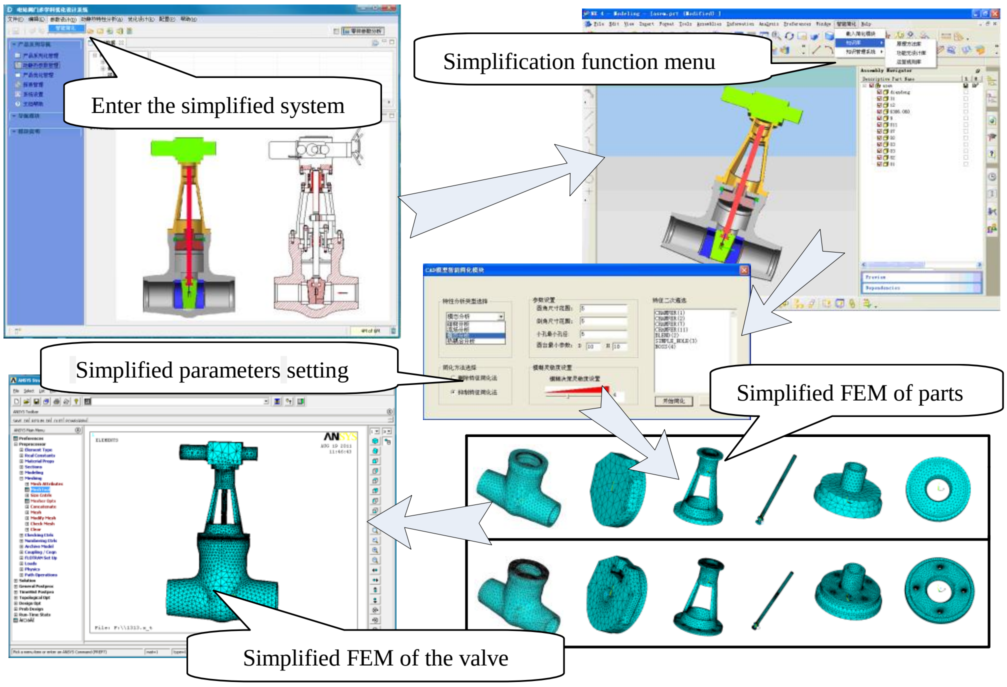

Figure 2. Rapid Simplification Process of Valve Model

2.2. Reuse Process of Valve Finite Element Analysis

In order to construct the characteristics reuse process of nuclear power valves, the whole system can adopt the initial design data of the valve product as the origin, including parametric modeling and assembly, multi-physics field analysis, structural optimization design of the nuclear power valve products. The process of generating the FEA reuse model contains numerical parameterization and finite element operation parameterization, which could make the command stream processing of the typical parts standardization.

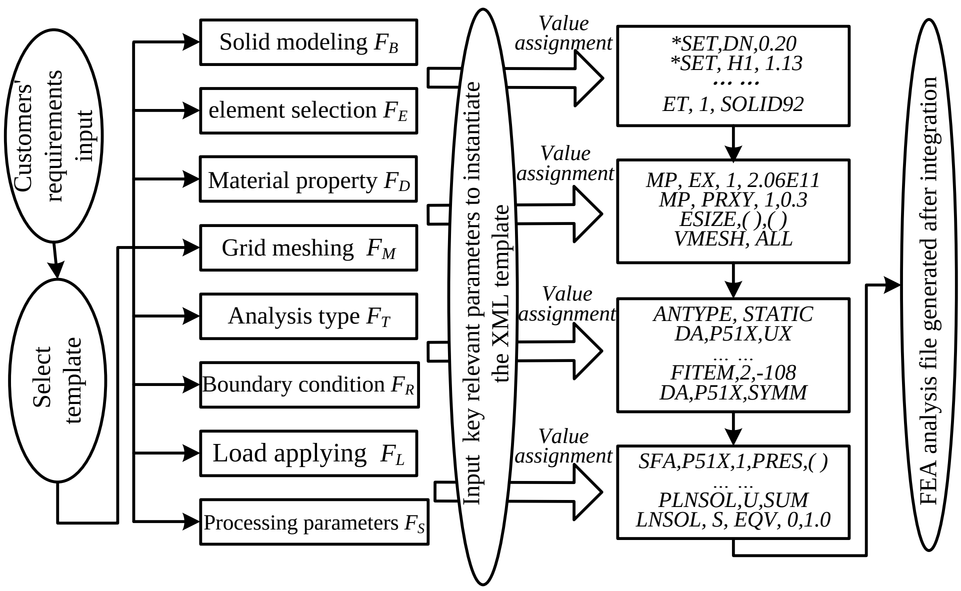

Figure 3. Data Transmission Flow Diagram of Reuse Process

The whole process of data transfer flow is shown in Figure 3. In XML reuse template file of product typical parts, the three basic processes of pre-treatment, solving and post-processing need to be defined. And then XML drive the analysis template to transmit design model from CAD to CAE. It eventually would form the product reuse model of finite element analysis[8-10]. In ANSYS environment, for instance, the generation of FEA reuse model is to compile the command files of FEA using ANSYS Parametric Design Language (APDL). According to each parameter name in the XML template file, the new parameter values can be wrote to APDL command file through the parameter name matches.

2.3. System Construction of Multi-Physical Field Analysis

As to the charact-eristics of components of the power station valves, establishing the database with model characteristic parameters is to be the memory of the bottom data, data transfer between design platforms is realized using the database, and resource sharing is implemented through the net. Figure 4 illustrates the system construction of multi-physical field analysis for nuclear power valves, which is divided into four parts: mechanical analysis, fluid mechanics analysis, thermal-mechanical coupled analysis and seismic analysis.

The main steps of the integration system can be classified in four parts:

(1) Parametric modeling and assembly of the valve products;

(2) Valve multi-physics field analysis;

(3) Valve structure optimization design;

(4) Knowledge management system.

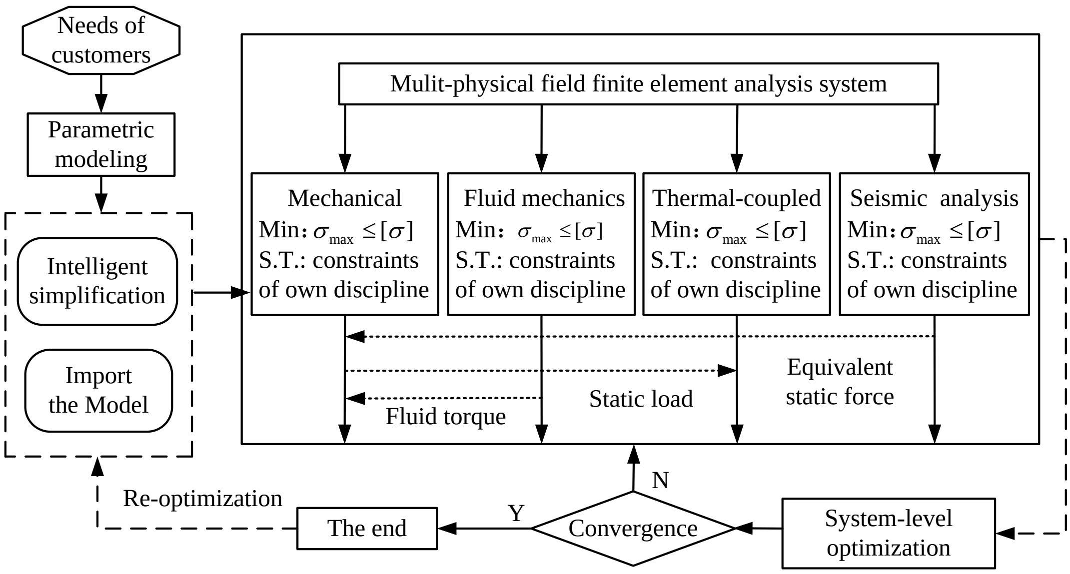

Figure 4. Digital Design Flow of Nuclear Power Valve Multi-Physical Field Analysis

The four kinds of analyses are totally based on the boundary and constrain condition of the actual working conditions so as to conform to the engineering practice. This kind of hierarchical model not only ensure the total optimization property of the entire product, but also give consideration to the independence of each subsystem so as to realize the collaboration design easily between different areas.

2.4. Configuration Process of Valve Design System

In order to provide a visual representation of the configuration process of the nuclear power valve design system, a module connection diagram is introduced here to describe the design process expressed. The Symbol "○" is adopted to express the module joint operations so as to show the relationship among modules.

For no coupling design, "circle S" is used to represent the simple addition of *FRs*; "circle C" signifies that *DPs* and *Ms* must be controlled according to the decoupling order of the design matrix; "circle F", used for a coupling design, shows it is in violation of the independence axiom.

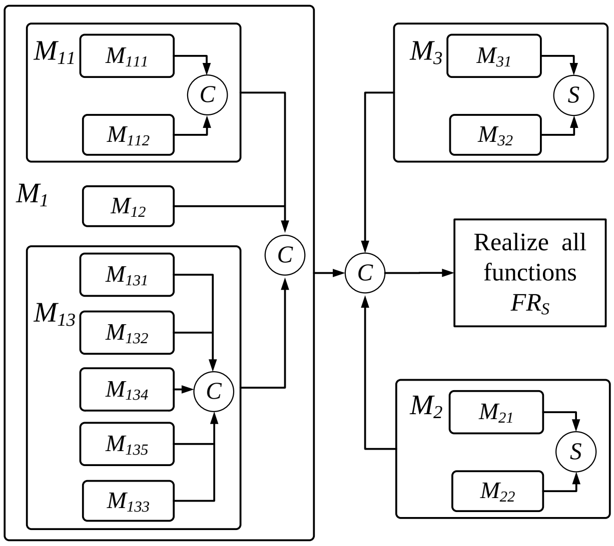

Figure 5. Valve Design Flow Chart

As shown in Figure 5, the design of the gate valve design complies with the sequence from the outside to the inside, which embodies the requirement of the axiomatic design. "*M*" in the figure stands for the design parameters. At the highest level, the nuclear power valve is composed of three sequential modules: M_1 (port opening and closing module) ——M_3 (aseismatic module) ——M_2 (sealing module). And M_1 can also be divided into three parts: M_{11} (open-close structure module) —— M_{12} (support structure module) —— M_{13} (driving structure module). M_{11} is composed of parallel module $M_{111}$and M_{112}, so the design of DP_{111} and DP_{112} can first be determined. By the same token, the whole valve structure design order can be obtained.

Valve design flow chart describes all the influence relationships of the design tasks. The design flow in the design system can be determined, the main interface of the integrated system for valve products is divided into four functional areas, namely, navigation buttons, valve design flow, management list area and valve parts display. In the valve design flow area, the design process of valve parts fully embodies design thought of the axiomatic principle, which ensures the objectivity and correctness of the valve restructuring design process[11,12]. And this process model can describe the whole process of valve design, which has a guiding role on the digital design and management. At the same time, the design process management model for the digital design behind provides the support of the valve data structure organization.

3. Integrated Design Method Application and Experimental Study

3.1. Application Process of the Integrated Design System

In order to comprehensively analyze the specific impact of the nuclear power valve under various influence factors, multi-physics field analysis of the whole valve, including structural static analysis, thermal-mechanical coupling analysis, flow field analysis, Seismic analysis, should be completed to predict the valve performance under different work conditions.

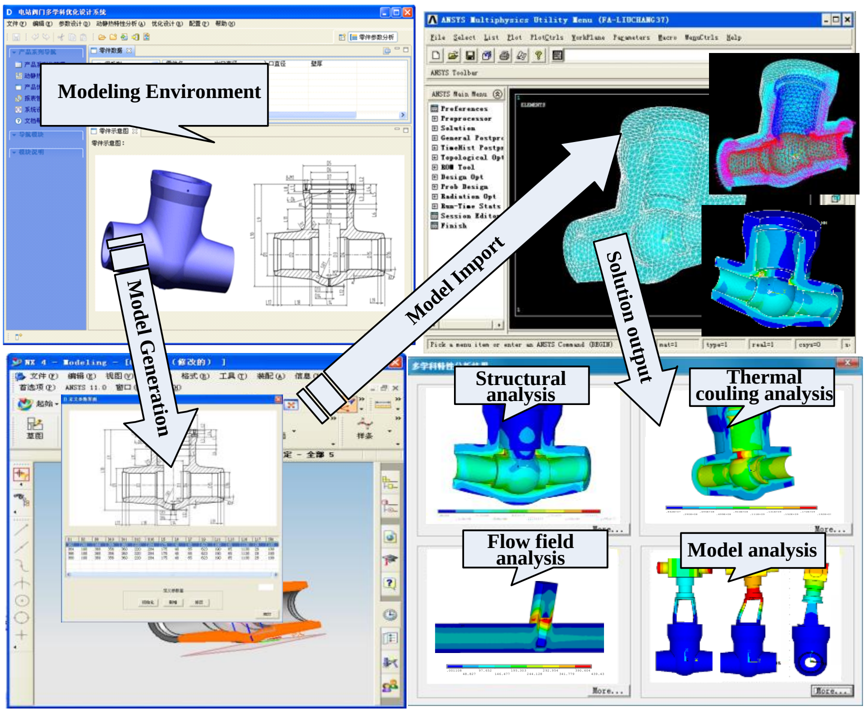

Figure 6. Main Process of the Integrated Design System

A kind of supercritical electric gate valve is selected as an example to study. The whole process is shown as Figure 6. First of all, designers should choose the analysis object in the part data lists and enter the model selection interface, and then can choose the appropriate model as a design template. After inputting all parameters of valve analysis, designers can get into the characteristics analysis platform by finite element analysis. Each analysis module manages the data of the CAE model, simulation analysis and post-processing graphic. Later, the analysis results will be displayed in the form of a chart. Finally, the optimum module will optimize the structure of the valve.

3.2. Strength and Sealing Test of the Valve

In order to verify the structural strength and sealing of the valve body, the hydrostatic test is used. The design pressure of the gate valve is 35.6MPa. The hydraulic pressure should be at least 1.5 times the maximum working pressure in the strength test, and be at least 1.1 times in the sealing test, so the experimental pressure is 54 MPa and 40 MPa, respectively. The hydraulic pressure should be loaded gradually from 38 MPa to 54 MPa, holding time for 5 min. Test results: in the pressurized process, there is no medium leakage phenomenon and welding crack on the body. In the whole sealing test, there is also no medium leakage phenomenon. Therefore, the test results show that the nuclear power valve body meets the work requirements in terms of the strength and sealing performance, and which confirms the correctness of the method and the calculation process.

4. Conclusion

To achieve fast response to the safety performance analysis of nuclear power valve, a kind of integrated design method of finite element analysis is proposed, and the experimental study on strength and sealing test of nuclear power valve is implemented. In view of the demands in multi-physics field analysis of valve products, the multi-physics field analysis process for valves is constructed. Heterogeneous information between CAD and FEA of valve models is expressed by using the universal data exchange technology. The validity of the analysis method above is verified by the valve strength and sealing tests, which results show that the nuclear power valve body meets the work requirements in terms of the strength and sealing performance. This research can provide the theoretical foundation and design method to design the high security nuclear valve, and important achievements can be made in improving capabilities for predicting safety performance.

Acknowledgements

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