Intersection of Engineering and Design: Exploration and Prospect of Finite Element Analysis in Design

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Abstract. Finite element analysis method is a widely used simulation test calculation method in engineering practice, and the design practice closely related to engineering practice. In recent years, more and more interdisciplinary knowledge and methods in different fields are integrated. Based on the comprehensive introduction of the finite element analysis method, this paper selects two cases from the author's practice and literature, respectively introduces and compares the application of finite element analysis method in engineering practice and design practice, discusses its different use ideas, and looks forward to the prospect of finite element analysis method in design practice.

Keywords: Finite element analysis · Design practice · Engineering practice · Design comparison · Design prospect

1 Introduction

As an independent subject, design has cross connection with many fields. On the one hand, design is constantly integrated with psychology, pure art, marketing, sociology and other disciplines. It is necessary to absorb discipline knowledge from these fields to discover new design problems, design objects and design methods. On the other hand, in a design practice, designers often face the dilemma that some slightly idealized design can not be implemented. This includes many problems from the aspect of engineering. Whether a design can be realized, produced and popularized, designers often evaluate it based on experience or appropriate experiments and research. This way can not express the estimated results accurately, but also pay a certain time cost, labor cost and material cost, reduce the design efficiency and extend the design cycle.

Closely related to design is engineering, such as industrial design corresponding to product production line, architectural design corresponding to civil engineering, landscape design corresponding to environmental construction, whether the project can be carried out smoothly is a decisive standard of whether the design can be realized [1]. Under the premise that design is far away from pure art and becomes an independent discipline, more and more other fields in engineering practice need to be taken into consideration by design. Finite element analysis method is a simulation analysis method

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often used in the field of mechanical engineering, which has a wide range of application, and has been continuously promoted in recent years [2]. Combined with the attributes of design practice, design and engineering have some common characteristics, which can give the finite element analysis more space to play a role.

2 Overview of Finite Element Analysis

Finite element analysis (FEA) is a kind of mathematical approximation method to simulate the real physical system, so as to calculate its geometric value or load under certain conditions. Specifically, from the perspective of the name, we can use a finite number of unknowns to approximate the real system with infinite unknowns by using simple and interactive elements (called finite number of elements).For example, the well-known method of dividing a circle into as many triangles as possible and then finding the sum of areas is similar to the principle of finite element analysis [3].

2.1 Brief Introduction of Finite Element Analysis Method

Finite element is the discrete element which can represent the real continuous domain. The finite element analysis method is known as the matrix approximation method, and it is mainly used in the structural strength calculation of aircraft. Because of its convenience, practicality, accuracy and effectiveness, it has aroused the interest of scientists engaged in mechanical research. Then, with the development and popularization of computer technology, this method has rapidly expanded from structural engineering strength analysis and calculation to the technical field of many disciplines, and has become a rich, extensive and efficient numerical analysis method [4].

It is a remarkable feature of finite element to solve the problems of mechanics, heat, fluid and magnetic field in computer engineering. Compared with the traditional experimental analysis, the current finite element method has the advantages of computer operation, high precision, convenient operation, detailed results and easy to understand. Finite element analysis method is now widely used in fluid mechanics, mechanical engineering, civil engineering, electrical engineering and other fields, its adaptability is very strong. For example, as far as thermal analysis is concerned, the target of thermal analysis can be internal combustion engine, turbine, heat exchanger, piping system and many other engineering components related to thermodynamics.

2.2 General Procedure of Finite Element Analysis

Today's mainstream finite element analysis software, such as ABAQUS, ANSYS, etc., from the whole analysis process of finite element method, the general analysis process includes four steps, namely, modeling, meshing, loading and solving. Their specific functions are as follows:

- **Modeling and importing:** with the help of other modeling software (such as SolidWorks, proe and other engineering 3D software), the simplified model is imported into the engineering environment of finite element analysis software. Some finite element analysis software will have its own modeling function, but generally the software dedicated to modeling will have higher modeling efficiency, and the connection between the software can be easily realized, so the auxiliary modeling software is usually used to build the model in advance.

- **Meshing:** meshing discretizes the continuous solution area into a group of finite elements which are connected with each other in a certain way. Mesh generation is the core and foundation of finite element analysis, and also the embodiment of the idea of "finite element".
- **Loading:** according to the basic properties of the workpiece and the working conditions, set the parameter values to load the simulation. This includes the material definition of the model and various parameters and states set according to the working conditions.
- **Solution:** select the appropriate image expression mode to analyze the results. Finite element analysis software can output different variables of the same calculation result and display them in different forms, including but not limited to chart, color, deformation, etc.

2.3 The Structure of FEA Software with ANSYS as an Example

Although the current mainstream finite element software is different in operation and interface, there are many similarities in functions and ideas.

Taking ANSYS software as an example, the software mainly includes three modules: pretreatment module, analysis and calculation module and post-processing module. The preprocessing module is responsible for creating or reading in the geometric model, providing solid modeling, meshing, defining material properties, and defining boundary constraints and loads. The analysis module specifically analyzes the structure, fluid dynamics, electromagnetic field, acoustic field, piezoelectric and multi physical field coupling. In addition, it can also analyze the sensitivity and optimization ability. The so-called post-processing is to display or output the results of data calculation in the form of charts and curves, which is convenient for users to view, generate reports, and test the results. This corresponds to the general flow of finite element analysis described above.

From the perspective of system division, the analysis system of ANSYS software includes solid analysis, fluid analysis, thermal analysis and electromagnetic field analysis. Among them, statics analysis includes the most commonly used statics analysis and dynamics analysis mainly used for modal analysis, as well as transient dynamics analysis and rigid body dynamics analysis; fluid analysis includes several acquired mainstream fluid analysis software and material forming simulation analysis mainly used for viscoelastic materials; thermal analysis includes steady-state thermal analysis and transient thermal analysis; fluid analysis includes static analysis and dynamic analysis mainly used for modal analysis; The function of electromagnetic field analysis is relatively simple. In addition to the analysis system, ANSYS also has a coupling system which can combine various analysis modules, and a design exploration system which can optimize the reliability and accuracy of the results through repeated iterative calculation.

2.4 Related Requirements in Design Practice

The functional properties of finite element analysis can easily lead to some associations about the exploration of design practice, such as the simulation analysis of some products that need to bear weight, such as the bearing capacity of tables and chairs, some analysis occasions involving thermal problems, such as the internal structure arrangement of water heater, and some products involving fluid flow, such as the pipe shape of humidifier.

But the biggest difference between design and engineering is that design is a kind of creative activity, while engineering is a concrete practice activity. Whether the finite element analysis method can play a role in design, and what is the difference between specific analysis means and analysis process planning can be obtained through specific case analysis and comparison.

3 One FEA Study Case in Engineering Practice

In view of the numerous practice of finite element analysis method in the field of engineering, including not limited to household appliances, vehicles and ships, textiles, liquid transportation, construction roads and so on, this paper selects a more representative case of mechanical parts for analysis: finite element analysis of service capacity of low temperature valve.

Low temperature materials such as petroleum, liquefied natural gas, liquid oxygen and liquid nitrogen are widely used in industry, and a large number of low temperature valves are required for analysis, transportation and storage [5]. Some industrial developed countries have begun to develop low-temperature steel and apply it to the production of low-temperature valves. According to different temperature levels, the corresponding low-temperature steel grades are used to manufacture all kinds of low-temperature valves, meeting the needs of low-temperature performance in working conditions [6]. The difficulty of cryogenic valve design is that the valve itself is difficult to achieve the purpose of test and design improvement through the actual working condition test experiment, so the finite element analysis method has a very strategic significance in the pilot test of ultra-low temperature valve. The stop valve is used to block and open the liquid flow in the pipeline [7]. It is faced with the working environment of repeated opening and closing and long-term liquid stamping. Its working performance and service life are often related to major safety and property problems.

3.1 Finite Element Analysis Process

The main process of the case is as follows:

① The three position model of the cut-off valve is established to simplify the assembly and import;

② The temperature distribution of ultra-low temperature cut-off valve for LNG was analyzed by finite element method under test (−196 °C) and working (−163 °C);

③ Based on the finite element analysis of the temperature distribution, the results were analyzed by thermal coupling treatment, and the deformation of the stop valve under each working condition was tested;

④ Carry out the finite element analysis of flow field analysis to check the distribution of pressure and velocity in the channel.

3.2 Display of Finite Element Analysis Results

As shown in Fig. 1, the figure is a simplified model of the stop valve. The low-temperature stop valve has a slender shape, and the valve body at the lower end is buried underground. The two outlets are the inlet and outlet of liquid nitrogen respectively. The movement of the valve disc inside controls the blocking and opening of the liquid flow; the upper part protrudes out of the ground and connects the sealing device and the handwheel controlling the movement of the valve disc (which has been omitted). The load mainly comes from the approximately constant temperature of the internal LNG (the heat exchange mode is the thermal steady state) and the normal temperature environment exposed in the air above (the heat exchange mode is the thermal convection), and the internal pressure comes from the liquid pressure of the LNG.

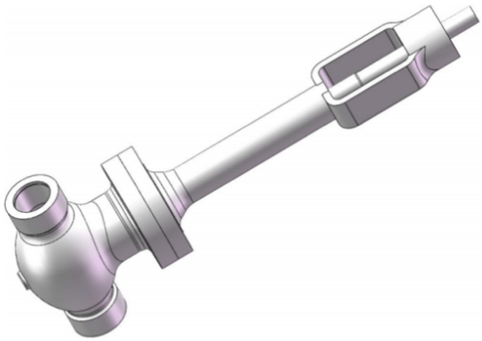

Fig. 1. Simplified model of globe valve

After defining and inputting these loading conditions, some results of finite element analysis are obtained, as shown in Fig. 2 and Fig. 3 (only the deformation calculation results at −163 °C and the velocity vector diagram in the flow field are selected). Under this condition, the maximum deformation of the low temperature valve is 0.85 mm, which is in line with the use error; under the condition of minimal disc opening, the maximum flow velocity in the valve is 1.23 m/s, and there is no extreme speed change area, which will not cause stress damage to the stop valve body, which meets the use requirements.

The case from the temperature, deformation, pressure, speed and other aspects of the service of the low temperature stop valve in engineering practice for a more accurate simulation prediction test, so as to preliminarily judge that the low temperature stop valve can meet the requirements of the test conditions and actual conditions. From the perspective of the case itself and the dimension of finite element analysis, it is more in line with the application characteristics of finite element in engineering practice.

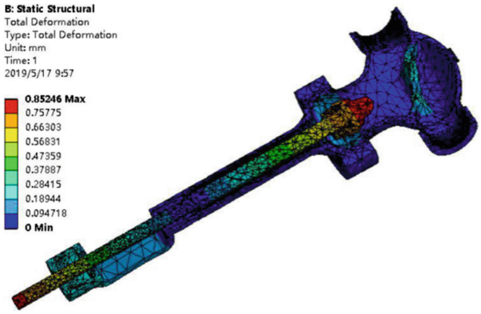

Fig. 2. Distribution of deformation of globe valve

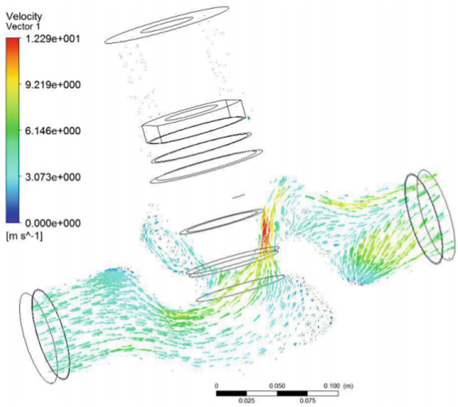

Fig. 3. Distribution of velocity vector in the flow field in the globe valve

4 One FEA Study Case in Design Practice

In the field of design, simulation analysis is an important means in the process of design planning, design comparison and design evaluation. The designer team is gradually getting rid of the traditional design evaluation methods, such as small batch production experiment, questionnaire survey, proofing and evaluation, and turning to some mathematical models and software analysis methods to enhance the feasibility and value of design. The finite element analysis can be regarded as a more effective method.

In the aspect of design practice, this paper selects cases from the literatures. The researchers focused on the problem of discomfort caused by long-time wearing protective helmets and the accumulation of heat in helmets in different sports such as skating or cycling [8]. Based on the review of existing literature and market research, researchers found the potential to improve the thermal comfort of helmets through convective heat transfer, which is usually achieved by passive ventilation [9, 10]. That is to say, the question of where and what kind of holes should be made in the helmet. It can be analyzed and compared by means of finite element analysis.

4.1 Finite Element Analysis Process

The main process of the case is as follows:

① In order to identify the natural high heat concentration area inside the helmet, a baseline concept helmet is generated in SolidWorks, and a finite element analysis is carried out in the form of steady-state thermal research in ANSYS.
② Next, according to the finite element analysis results of heat, four sections are selected, and a series of conceptual openings are carried out on the basis of the baseline model, which represent the different hole structures of the front, back and side three general hole positions.
③ Next, combine the best performing conceptual design into a single model and test. In all the test concept designs, four separate sections measure the flow velocity at the set detection point. Based on the collected data, the ventilation performance of various conceptual designs is discussed and verified compared with the baseline model.

4.2 Evaluate of Finite Element Analysis Results

The calculation reveals the changing trend between the general hole location and the local ventilation efficiency, as well as the differences between the individual concepts of each hole location [11]. The analysis results show that the ventilation condition of three holes in the front, one hole in the rear and two holes in the side is the best, that is to say, combined with the strong personal concept of the designer, the design does not necessarily have excellent performance in ventilation and heat dissipation [12].

In this case, by controlling the combination of the number and direction of the holes on the helmet, the change of the airflow velocity of the gas passing through the helmet is studied, so as to detect the heat dissipation ability of the helmet under different combinations. For the concept of "opening holes on helmet can dissipate heat", the heat dissipation capacity of different combinations of openings is analyzed and compared quantitatively by means of finite element thermodynamics and fluid mechanics, and a more optimized design result is obtained.

5 Discussion on the Application of FEA in Design

From the above two cases, it can be seen that in the design practice and engineering practice, although we can rely on the finite element analysis to achieve a certain purpose in varying degrees, there are still many differences in methods and intentions. Finite element analysis is a kind of simulation analysis, which has obvious advantages and disadvantages.

5.1 Comparison of FEA Methods in Engineering and Design

First of all, the finite element analysis in engineering environment has a clear definition for the variable conditions such as material, size and working load. Most of the cases are directly from the drawing to generate the model, and then directly from the working condition measurement to obtain the temperature, pressure, magnetic field strength, speed and other data for loading, which has a certain direct reliability. From the analysis results, we can rely on a single test data for evaluation and judgment. This is because the output is more intuitive, and most of them are the values of temperature, deformation, etc., which can be evaluated according to certain applicable standards for bearing capacity and design rationality. This is also the reason for the popularity of finite element analysis in engineering practice and its own advantages, that is, the intuitive and relatively accurate nature of simulation test.

The application of finite element analysis in design practice is relatively circuitous. Compared with the direct use of finite element analysis method for design calculation and evaluation, it is more like using finite element analysis method as an auxiliary tool to achieve a certain comprehensive evaluation means. For example, in the above case, the slightly fuzzy concept of "helmet ventilation capacity" is converted into "the size of the velocity change caused by the airflow through different combinations of openings", so as to expand the experimental layout, and show the "ventilation capacity" quantitatively through the finite element analysis method, and select the optimal scheme according to the results. In such a transformation of thinking, we can see that design thinking is often more emotional and human, rather than straightforward and accurate in engineering practice. Therefore, the design practice needs to introduce the method of finite element thinking, transform the perceptual design cognition into a numerical calculation model, and set a reasonable analysis plan.

In the final analysis, design is a creative activity to serve people, so it is inevitable that there will be many perceptual design goals, perceptual evaluation criteria and perceptual design concepts. To transform these perceptual factors into reasonable rational expression may not only be the introduction of finite element analysis into design ideas, but also the more efficient transformation of design practice into engineering practice and continuous feedback This paper focuses on the method of optimizing and updating design concept.

5.2 Advantages and Disadvantages of FEA in Design

However, it is worth noting that the finite element analysis method has the limitations of the simulation analysis itself, such as the necessary simplification in the analysis process will cause certain errors, the mesh generation of the finite element itself can not be extremely accurate, and the complex and changeable human factors in the real use process, all of which will lead to the simulation test results will eventually stay in the same place This is true for the relatively stylized production practice, and there may be more irresistible distortion in the design practice with more human factors.

6 Summary and Prospect

The advantage of finite element analysis itself lies in the more accurate calculation results, a wider range of applications, because with the help of computer-aided testing can greatly improve the efficiency and cost, which are common in both design practice and engineering practice. When we look at FEA from a design perspective, we can find that

FEA can quantitatively express some perceptual design concepts, such as "comfortable", "strong", "durable", "elastic", "warm" and "fast", so as to serve for design evaluation and design update.

Simply put, we can imagine some direct application of finite element analysis method, such as the service life calculation of electrical appliances, the rational evaluation of temperature occasions in architectural design, the evaluation of the bearing capacity of furniture such as tables and chairs, etc.; in-depth discussion, we can also use the finite element analysis method to carry out more design analysis and exploration, such as the impact of design products on people's senses, design cycle In this paper, we only discuss the impact on design cost and whether the inherent design paradigm can break through its prototype.

In short, the finite element analysis method can be used as the intersection of design and engineering, and it can be applied to the process of more efficient and reasonable transformation of design practice into engineering practice, engineering practice feedback, optimization and updating of design practice. We also have reason to believe that in the future design development, there will be more interdisciplinary fields and methods applied to design activities.

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