Structural Analysis and Optimization Design of Laminated Bent-wood Chair

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Abstract. By means of computer-aided analysis, the structural mechanical strength of laminated bent-wood chair, which represents the mainstream product of contemporary furniture design, has been analysed, and the mechanical properties prediction and optimization design model of laminated bent-wood chair are constructed; the theoretical basis and method for the application of finite element method in the design and manufacture of laminated bent-wood chair are considered, and the optimum design for the structure and strength design of curved-surface furniture is discussed. Research shows that this study will effectively reduce the raw materials and production costs consumed in the development and utilization of new furniture products, shorten research and development cycle, improve labour productivity, and provide new test and methodology for furniture design and manufacturing industry.

1. Introduction

Along with the economic progress and the development of science and technology, log competition in the world timber market is fierce. Timber output shrinks, furniture industry develops rapidly, and furniture standardization process is expanding day by day [1]. In the world, the development of furniture tends to be high-tech. From the perspective of furniture design and manufacture, modern furniture structure is becoming more and more concise, paying attention to the organic structure and artistic aesthetic feeling [2, 3].

There are many kinds of modern furniture materials, and the materials, categories and colours tend to be diversified. In recent years, the furniture industry has developed rapidly in the application of new technologies and new materials, and the market has put forward remarkable requirements for the production and functionality of furniture: equipment with excellent performance for material protection, scientific structural analysis method. In China, the strength analysis of furniture structure is still based on traditional calculation methods or test methods, and computer aided design and analysis methods have been used abroad to calculate. In order to comprehensively enhance the level of Chinese furniture design, to transform China from a big furniture manufacturing country to a strong furniture design country. It is necessary to guide furniture design and manufacture in a more scientific way.

With the diversification of contemporary furniture design, more requirements for auxiliary analysis of furniture design are put forward. This research will be applied to the practice of laminated bent-wood chair design and manufacturing, which will effectively reduce the raw materials and production costs consumed in the development and utilization of new furniture products, shorten the research and
development cycle, improve labour productivity, and provide new testing and methodology for 
furniture design and manufacturing industry.

2. Research methods and technology roadmap
Finite element method (FEM), is an efficient numerical method, which can effectively disperse the 
differential equation, compile a program, and solve it with the aid of computer [4, 5]. With the rapid 
development of computer technology, finite element method (FEM) has become the most effective 
method for structural analysis [6]. Laminated bent-wood chair has a special technology, it is bended to 
the desired radian by high temperature and high pressure, shape is changeable and the material has a 
certain creep, its structure and strength can be studied by finite element method [7].

2.1. Analysis of research method
• The structural strength of laminated bent-wood chair is analysed by finite element method, 
and the mechanical model is established.
• The actual loading condition of laminated bent-wood chair is analysed by simulation analysis.
• The force of laminated bent-wood chair is measured by the test method in actual use.
• The optimum design method is used to optimize the design of laminated bent-wood chair.

2.2. Analysis of technology roadmap
The technology roadmap as show in figure 1.

3. Research contents

3.1. Establishment of mechanical model
The geometric model of the laminated bent-wood chair is established by using the plate-shell finite 
element method, and the mechanical model of the laminated bent-wood chair is established by 
choosing the appropriate element type, restraint and loading mode.

3.2. Mechanical analysis
Using the established laminated bent-wood chair mechanics model, the following mechanical analysis 
is carried out for the chair:
• When simulating normal sitting posture, stress distribution of chairs.
• Simulating the stress of chair under impact load.
• Simulate the force of a man sitting on a bent wooden chair, the force of front, rear, left and 
right of the chair is warped.
3.3. Actual measurement
The actual measurement method is used to measure the various loads of laminated bent-wood chair under the above conditions, and the data are analysed reasonably.

3.4. Comparison and amendment
The measured value is compared with the simulated value, and then the mechanical model is corrected.

3.5. Optimal design
According to the established mechanical model, to optimize of structural design on laminated bent-wood chair, and make a comparative analysis.

4. Results and discussion
At home and abroad, the application of finite element method in furniture design is mainly concentrated on the form of furniture which can be simplified as frame, or the strength analysis of furniture joints and components, or local optimization design [8, 9]. With the development of modern art design and modelling theory, the mainstream of furniture modelling is sculpture-like furniture modelling design, such as bionic design, ecological design, organic furniture design, and so on. The structural analysis and optimization design of such furniture has not been reported and is imperative.

Through the review of finite element method in furniture structure design, it can be seen that the analysis of furniture structure design is developed and perfected on the basis of material mechanics, theoretical mechanics, engineering mechanics, computer and mathematical methods. The research on furniture structure and performance in developed countries is more in-depth than in China, the study of furniture design theory in China only stays on the surface of aesthetics, art and so on, the overall research on structure and modelling is rather weak. Studies have shown that research should be strengthened in the following aspects:

4.1. Methods of furniture design
The research on furniture form at home and abroad mostly concentrates on the analysis method which is simplified as frame type, and the curved surface furniture with more complicated shape should be studied deeply (shell furniture, bionic furniture, organic furniture), to meet the development requirements of furniture design.

4.2. Furniture design should embody the concept of system
Optimal design based on structural design and ergonomics and aesthetics is a comprehensive skill that furniture designers and furniture engineers should learn and master. The cultivation of sophisticated talents in furniture design should be all-round, and this is also the need to adapt to social development.

4.3. Further study of furniture design theory
Comprehensive optimization of furniture shape, structure and production technology is an inevitable trend in the future.

To sum up, in accordance with the development of furniture trend, the laminated bent-wood chair is optimized by finite element method, the structural strength analysis and optimization design of laminated bent-wood chair are carried out; find the weakest stress of laminated bent-wood chair in normal use, and to make reasonable correction and enhancement. It provides an effective method for the structural analysis of curved furniture with complex shapes (shell furniture, bionic furniture, organic furniture), and will provide scientific ideas for improving the level of furniture design in China.
5. Conclusion

Based on the traditional calculation and test methods, the structure and strength of laminated bent-wood chair can be studied by finite element method, reliable data can be obtained, furniture design and manufacturing methods can be optimized, and the function of raw materials and user experience design can be maximized.

Previous studies at home and abroad focused on the stress analysis of furniture joints or panel furniture. This study intends to analyze curved shape furniture, and selects representative laminated bent-wood chair for analysis.”

Combined with the actual use of the chair, this paper analysed the force on chairs such as instantaneous stress state, warping or swaying; fully considering the force situation of curved surface modeling furniture in use, carrying on the scientific conception and analysis, this research is the frontier thinking and practice of furniture design and manufacture.

References

[1] Haines, Charles M. (1990) The industrialization of wood: The transformation of a material. University of Delaware, Newark.
[2] Han, Youngho. (2009) A Study on the Developmental Stage of characteristics of Furniture Design by Alvar Aalto. Journal of the Korea Intitute of the spatial design, 4: 53-61.
[3] Han, Youngho. (2004) A Study on Characteristics of Making Process of Bentwood Furniture. Korean Institute of Interior Design Journal, 13: 140-149.
[4] Nestorović, Biserka. Grbac, Ivica. Nestorović, Predrag. (2013) Numerical analysis of laminated wood structures - Chairs by application of FEA. In: 24th International Scientific Conference: Wood is Good - User Oriented Material, Technology and Design, Proceedings. pp. 101-109.
[5] Mishra, S. Sain, M. (2007) Strength analysis of chair base from wood plastic composites by finite element method. Materials Research Innovations, 11: 47-49.
[6] Kasal, Ali. Birgul, Recep. Erdil, Yusuf Ziya. (2006) Determination of the strength performance of chair frames constructed of solid wood and wood composites. Forest Products Journal, 56: 55-60.
[7] Mishra, S. Sain, M. (2007) Strength analysis of chair base from wood plastic composites by finite element method. Materials Research Innovations, 11: 47-49.
[8] Wengang, H. Weilian, F. Huiyuan, G. (2018) Optimal design of stretchers positions of mortise and tenon joint chair. Wood Research, 63: 505-516.
[9] Kasal, Ali. Smardzewski, Jerzy. Kuskun, Tolga. Erdil, Yusuf Ziya. (2016) Numerical analyses of various sizes of mortise and tenon furniture joints. BioResources, 11: 6836-6853.