Wheel Hub Material Selection through Finite Element Analysis based on Reverse Engineering

Junzhen Liu, Junyu Liu, Tingjie Liu, Runhua Luo and Xianghui Zhan*

School of Zhuhai College of Jilin University, Zhuhai, China

*Corresponding author e-mail: zhanxianghui@jluzh.edu.cn

Abstract. This paper aims to analyze the existing wheel hubs and build a three-digit wheel hub model by combining forward and reverse mixing modeling. The Geomagic Wrap and Geomagic Control X software are used to collect the hub's geometric features, and the construction of the solid model is completed quickly. The precision analysis of the reconstructed solid model was carried out, which verified the method's effectiveness. The 3D digital model is imported into NX software, and NX software is used to carry out finite element analysis. The best material is selected through the results of the simulation data calculation. Finally, the hub finite element's static analysis and design strength requirements are compared to verify the reverse design method's feasibility.

1. Introduction

With the rapid development of the automotive industry, automotive materials tend to be lightweight, high performance, safety development. The wheel hub as one of the automobile's parts, the choice of its materials is an essential link in the light evolution of the automobile industry. In this paper, more excellent hub materials are selected to reduce the weight of hub materials under the same volume, to achieve lightweight.

The author randomly selects the hub in the market to model. The hub's three-digit model is mainly built by the three-dimensional scanner, Geomagic Wrap software, and Geomagic Control X software. The model is compared with the point cloud data to ensure the accuracy of the center point model. Then the hub is designed with the ideal model in NX-CAE. Choose steel, aluminum alloy, magnesium alloy, and carbon fiber as automobile hub materials for fatigue performance comparison. At the same time, from the material property point of view, select the best material as the automobile hub material.

2. Reverse design method of the automobile wheel hub

In this paper, One 15-inch wheel hub is randomly selected as the research object. The HSACN handheld laser 3D scanner purchased on campus is used to scan the wheel hub. The Geomagic Wrap was imported to optimize the data and complete the packaging. And import the resulting model into Geomagic Design X to achieve 3D modeling. The model was compared with the original scan. The process is shown in Fig. 1 [1, 2].
2.1. Collection of point cloud data of the hub

The author selects HSACN handheld laser scanner purchased in the university to collect the hub's point cloud data, flow chart of cloud data acquisition as shown in Fig. 2 [3, 4].

First of all, the scanner distance correction to improve the accuracy of the scanner. Since the purchased hub has black spray paint, as shown in Fig. 3, an imaging agent should be applied to the hub surface before scanning. Then the hub surface should be uniformly affixed with registration points with an interval of about 3cm, which are used to obtain the scanner information. The wheel hub is placed on the table with black cloth for scanning, as shown in Fig. 4. Due to the surface's complexity during the scanning process, the scanner's angle needs to be adjusted many times. The marking points need to be added appropriately to improve the integrity of the high point cloud data set. After scanning, save the scanned data file in a format of *.ASC.

2.2. Optimize hub point cloud data and perform surface encapsulation

The Geomagic Wrap software will import the saved .ASC file first, as shown in Fig. 5. The point cloud will be optimized by removing various points and other operations, and the grid doctor will be used to obtain the ideal hub data surface, as shown in Fig. 6. Save the file in a format of *.ASC.
2.3. Hub modeling
Import the packaged ASC file into the Geomagic Design X software. Firstly, the model's field is divided to facilitate subsequent operations such as 3D sketch construction and surface fitting.

Find an appropriate angle for the model's plane projection to ensure that the hub's maximum profile can be projected on the reference plane. Optimize the contour's rotation curve and select the center axis for rotation to obtain the hub prototype, as shown in Fig. 7, and conduct an error coloring analysis for the hub prototype. Ensure that the model for the hub is accurate, as shown in Fig. 8.

![Figure 7. Hub prototype](image1)

![Figure 8. Hub prototype error](image2)

Through the sketch projection, the round hole in the hub center can be obtained. As shown in Fig. 9, the hub's spoke surface is very complex, so it is necessary to adopt the method of surface fitting. The spokes' area is selected for surface fitting, and 16 groups of different surfaces are obtained by cutting with the hub's prototype. By comparing other spokes, the optimal two characters were selected as the model's surface bodies and cut with the hub prototype, as shown in Fig. 10.

![Figure 9. The side of the wheel hub](image3)

![Figure 10. The back of the wheel hub](image4)

Through the steps of surface fitting and construction, the 3D hub model is finally obtained, as shown in Fig. 11. Then, by precision analysis and comparison of the scanned data model, the deviation and accuracy between the observed data and the designed surface are checked, as shown in Fig. 12 [5].

![Figure 11. A 3D model of wheel hub](image5)

![Figure 12. Error analysis shader diagram](image6)

3. Statics structure analysis of wheel hub
In order to verify the mechanical properties of the reconstructed automobile hub model, the finite element analysis of the model is needed. The finite element software is used to analyze and calculate the corresponding stress values to verify whether the reverse design meets the requirements. The wheel
hub's commonly used materials are AZ91 magnesium alloy, carbon steel, A356 aluminum alloy, and Toray carbon fiber T700-12K. The mechanical properties of the materials are shown in Table 1 [6].

### Table 1. Mechanical properties of materials

| Number | Material          | Rho (g/cm³) | Young's modulus E (GPa) | Poisson's ratio of μ | The yield strength σ₀ (MPa) | Ultimate tensile strength σₚ (MPa) |
|--------|-------------------|-------------|-------------------------|---------------------|-----------------------------|-----------------------------------|
| 1      | Carbon steel      | 7.86        | 200                     | 0.26                | 400                         | 517                               |
| 2      | A356 aluminum alloy | 2.67       | 70                      | 0.33                | 229                         | 263                               |
| 3      | AZ91 magnesium alloy | 1.78       | 45                      | 0.35                | 160                         | 280                               |
| 4      | Toray carbon fiber T700-12K | 1.76 | 230                     | 0.307               | N/A                         | 3500                              |

3.1. The introduction of the geometric model and the establishment of the finite element model

In this study, some model features of the wheel hub 3D model on the rim were deleted and saved as a file in the format of *.stp, which was imported into the finite element analysis module with NX UG for the division of finite element mesh. The author adopts the tetrahedral mesh model with 252,041 units and 73,386 nodes, as shown in Fig.13.

![Figure 13. Finite element mesh division of hub](image)

3.2. Material parameter setting

In this study, the divided finite element model was pre-analyzed in the NX UG finite element module, and its material properties are assigned according to the parameters in Table 1.

3.3. The strength analysis of the hub

The experimental device in this study is a rotating hub. Before the test began, the author assembled the tire and the wheel hub to ensure that the tire's rated load was the same as the wheel hub's nominal value. When applying radial load Fr to the hub, the hub should also be rotated and in contact with the tire's outer surface. Before the test (unit: KPa), the tire pressure should not be lower than the tire's maximum load pressure. The radial load force Fr applied can be determined as: [7]

\[ Fr = F_v \times k, \quad (4.1) \]

Fr represents the radial load (N) received by the hub, Fv means the maximum load (N) acquired by the hub in the vertical direction; K is the enhancement experiment coefficient.

For this study, the hub's radial load is divided into two parts: the external load distributed in a semi-cosine function. The other is the pneumatic load generated by the tire. The force sector of the radial load is shown in Fig. 14.
Figure 14. Fan diagram of the forces on radial loads

According to the schematic diagram of radial load and reference materials, the calculation formula of the radial load loading function is as follows:

\[ P = F_r \cdot \frac{(\cos \theta - \cos 0)}{2b} \cdot r \cdot 2\sin 0 \]  \hspace{1cm} (4.3)

According to expression 4.1, the hub's radial test load is 10,000 N. Since the force on the hub is not linearly distributed but quadratic in reality. The grid of loads on the hub at 120 degrees can be divided into 12 parts and symmetrical. Based on the idea and expression of the finite element 4.3, the variation of radial load P with the angle can be obtained, as shown in Table 2 below:

| θ  | P      |
|----|--------|
| 0° | 0.344  |
| 10°| 0.333  |
| 20°| 0.298  |
| 30°| 0.251  |
| 40°| 0.183  |
| 50°| 0.098  |
| 60°| 0    |

According to the hub's actual stress, the finite element analysis module of computer-aided SOFTWARE NX-CAE applies a load to the hub. The hub is subjected to a radial load with an angle of 120° and a pneumatic load on the entire circumference. The load is shown in Fig. 15.

The maximum stress value of carbon steel is 28.34MPa, A356 aluminum alloy 28.34MPa, AZ91 magnesium alloy 28.32MPa, and Toray T700-12K carbon fiber 28.35MPa. According to the international standard of radial load, the radial fatigue limit of carbon steel is 233MPa, A356 aluminum alloy is 118MPa, AZ91 magnesium alloy is 126MPa, and Toray T700-12K carbon fiber is 1575MPa. It is proved that the model can meet the strength requirement under the limit static load, and the reverse design can ensure safety in daily use [8].

4. Conclusion
In this paper, parametric reverse engineering and finite element analysis of the automobile hub is studied. The hub's structural features are disassembled and extracted, and the solid model is quickly reconstructed through forward and reverse modeling. Using error analysis and the UG NX finite element module, reverse engineering's feasibility and quality in this paper are verified from multiple directions.

The results show that this method can effectively improve the modeling efficiency, optimize the structure of the model, and improve the speed and quality of forwarding and reverse design of products.

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References
[1] Shibo Ma, Shuai Liang, Shuangjie Zhang, Huajun Yan, Inquiry for repair method of damaged impeller based on forward and reverse hybrid modeling[J], Modern Manufacturing Engineering. 2020(08):114-119.
[2] Matej Paulic, Tomaz Irgolic, Joze Balic, et al, Reverse Engineering of Parts with Optical Scanning and Additive Manufacturing, Procedia Engineering. 2014, 69:795-803.
[3] Zhao Weiguo, Gou He, Wang Yan, Wang Maomao, Liu Luxin, Research the building model based on reverse engineering and technology of surface modeling[J], Modern Manufacturing
Engineering. 2014(08):78-82.

[4] Feng Chaochao, Chen Siyuan, Yang Xuerong, Luo Shaoming, Forward and Reverse Hybrid Modeling Based on Geomagic Design X[J], Machine Tool & Hydraulics. 2017, 45(17):157-160.

[5] Guo Hengya, Huang Ming, Li Hongli, Reverse Surface Reconstruction and Mould Design Method Based on Imageware & UG[J], Engineering Plastics Application. [17]2015, 43(01):76-79.

[6] Zhanguang Zheng, Teng Sun, Xiyong Xu, Shuai Yuan, Numerical simulation of steel wheel dynamic cornering fatigue test, Engineering Failure Analysis. 2014, 39:124-134.

[7] Chen Chao, Zheng Pan, Li Mengmeng, Wen Zheqing, Research on Reverse Modeling of Marine Propeller[J], Machinery Design & Manufacture. 2020(09):271-275.

[8] Tan Ming, Gu Bin, Application of UG NX Finite Element Analysis in the Design of Aluminium Alloy Automobile Wheel Hub[J], Bulletin of Science and Technology. 2016, 32(09):158-161+166.