Simulation and experimental research of digital manufacturing based on reverse engineering

Junbing Pan *, Jiazhong Xu, Chenliang Zhang
Shaanxi Institute of Technology, Xi’an, China

*Corresponding author e-mail: panjunbing@stu.shzu.edu.cn

Abstract. Reverse innovative design has long been an important subject in the engineering field. In this paper, two different-shaped desk lamp stands were studied. The point cloud data of the stands was collected by using Win3D scanner and Geomagic Wrap software. Then, after facial processing of the data, reverse innovation of the facial data was performed through the reverse design software of Geomagic Design X to develop a new desk lamp stand that can satisfy engineering applications. It is actually an upgrading of the appearance of the original desk lamp stand. Finally, the numerical control program of the new desk lamp stand was completed through the processing module of UG software, and the program was verified by simulation and was used for experimental sample machining. Experimental results showed that the difference between the processed sample and the research model was less than 0.02 mm, indicating that the new design can satisfy engineering requirements and replace the original desk lamp stand. This means that reverse design technology is highly compatible with machining technology, which can shorten the innovative design period of product.

1. Introduction
In recent years, great achievements have been made in the machinery field in China, especially in numerical control technology [1-3]. With the continuous integration of computer technology into the processing field, mechanical design gradually transits from traditional forward design to reverse design [4-7]. Reverse design is a process of re-innovation on the existing model, which processes the original model into a digital model by scanning [8-11]. Reverse design is especially useful in building curved models with complicated shapes. Today, it is widely applied in the optimal and innovative designs as well as parts repairing of military and civilian products such as airplanes, cars, electrical appliances, motorcycles, and so on [12-14]. Reverse design has gradually evolved as an important means of digestion and absorption of advanced technology [15, 16]. This paper studied two different-shaped desk lamp stands based on reverse design method, and innovatively designed a new desk lamp stand that can meet engineering needs. Then the new stand was machined and tested. This study can provide reference for the product upgrade and design for Chinese enterprises, thus enhancing the industrialization process of China.
2. Materials and methods

2.1. Design requirements and test materials

Figure 1. Desk lamp stands tested

The two different curved desk lamp stands studied in this paper are shown as Figure 1. No. 1 desk lamp stand is an integrated design (Figure 1a) with flat bottom, which should be put on flat surface; No. 2 desk lamp stand has a clamp (Figure 1b). The upper part and lower part of the clamp are hinged by pins, using springs to provide elastic force for the opening and closing of the clamp. This desk lamp stand is usually used by clamping on table corner or put directly on a flat surface. The generatrixes of No. 1 and No. 2 desk lamp stands are shown as Figure 1c and Figure 1d, respectively. As shown, No. 1 stand showed stronger streamline appearance and visual impact than No. 2 stand, but No. 2 is more adaptable to the working environment. By combining the advantages of the two desk lamp stands, this study aims to design a new lamp stand with more reasonable appearance and structure to obtain a better market competitiveness. The specific design method is as follows: replace the upper curve surface of No. 2 stand with No. 1 stand which features better curve structure, that is, to upgrade the appearance of No. 2 stand while maintaining its adaptability to the working environment. The software and hardware used in this study include Win3D laser scanner, Geomagic Wrap for point cloud processing, Geomagic Design X for reverse modeling, UG programming software, TR200 surfagauge, VMC 1060 machining center, CONTURA G2 three coordinates measuring instrument, necessary knives, milling cutter, and aluminium alloy blank, etc.

Figure 2. Point cloud data collection of desk lamp stand
2.2. Test method

2.2.1. Point cloud processing and digital model building. Before point cloud collection, adjust the collection error of Win3D scanner to less than 0.02 mm; collect the point cloud data of No. 1 and No. 2 desk lamp stands respectively based on their characteristic calibration points, as shown in Figure 2. Use Geomagic Wrap to make lattice repairing, surface smoothing and other treatments. Then pack them as lamellar parameterization model and save in *.stl format; import the *.stl files of No. 1 and No. 2 desk lamp stands successively into Geomagic Design X for integration innovation (Figure 3) to design a new upper clamp of No. 2 desk lamp stand. The operation process is shown as Figure 4.

Error analysis was conducted on the new upper clamp model (Figure 5). With error smaller than 0.02 mm on curved surface, the curved shape of No. 1 desk clamp stand can be accurately restored. In order to test the working performance of the model, samples of the newly designed desk clamp stand was machined to test the volume error and matching degree with the lower clamp of No. 2 desk clamp stand. The new upper clamp model was exported as universal three dimensional format of *.step for future programming and simulation processing in UG software.
2.2.2. **Automatic programming.** Proper-sized bulk aluminum alloy was selected as machining blank for numerical control programming (Figure 6). The machining of the new upper clamp model can be completed on three-axis numerical control machining center by cutting the two sides of the clamp part successively. This study used VMC 1060 three-axis machining center for machining test. Before machining, the model files in *.step format of the new upper clamp model were imported in UG software for numerical control programming and virtual machining. The cutting tool path during the virtual machining is completely overlapped with that in real machining. If no failure like knife breaking happens in virtual machining, the program can be exported for real machining.

The machining of the two sides of the new upper clamp was conducted in two steps of rough machining and fine machining. The reverse side was machined first to ensure the surface precision of the upper clamp (Figure 7a and Figure 7b); then turn over the workpiece to machine the front side (Figure 7c and Figure 7d). The reduction of cutting resistance during the machining process can improve the cutting precision of the workpiece. Therefore, we used shank cutter and set low rotation speed and deep feed for the rough machining of the curved face, leaving 0.5 mm for fine machining. During the fine machining, the flat face was machined with shank cutter and the curved face was treated with ball cutter. This part of machining was completed at high speed (low feed and high rotation speed). After proper simulation of the trajectory of the cutters in each process, the corresponding UG program was post-processed to generate numerical control program code for machine tool cutting.

![a. Reverse side rough machining](image-a)

![b. Reverse side fine machining](image-b)

![c. Front side rough machining](image-c)

![d. Front side fine machining](image-d)

**Figure 7.** Machining technology

2.2.3. **Machining test.** The engineering application performance of the reverse innovative design can be verified by investigating the error of the new upper clamp sample and its matching degree with the lower clamp of No. 2 desk lamp stand, thus providing reference for innovative design of the product. On this basis, the sample was machined and tested at the CNC machining center training base of Shaanxi Institute of Technology on March 22, 2020. Supporting devices, such as cutters, spacers and fixtures, were prepared based on the machining requirements. Then, turn on the VMC 1060 three-axis machining center and preheat for 10 min. Next, put in the clamp workpiece and install all the machining cutters in the cutter base and complete tool setting operation. After that, input the numerical control program for automatic machining. The test site is shown as Figure 8. After machining, use CONTURA G2 three
coordinates measuring instrument to test the relative error between the machined model and the theoretical model of the new upper clamp, and the error was shown to be less than 0.02 mm. Meanwhile, use TR200 surfagauge to measure the surface roughness. Result showed that the roughness on the curved surface reached Ra3.2, which can satisfy the engineering requirements in dimensional accuracy and surface quality, indicating that the new design can replace the original upper clamp of No. 2 desk lamp stand (Figure 9).

3. Results and discussions

3.1. Design requirements and test materials
Reverse modeling can build a digital model for existing model(s) through scanning technique and realize the innovative design. This study performed the secondary innovative design through curved surface integration in the reverse modeling software of Geomagic Design X after scanning two different-structured desk lamp stands, and upgraded the appearance of No. 2 desk lamp stand. This design method mainly used scanner to collect the point cloud data of the model for reverse modeling. This model can be also multiply designed through 3D modeling software. Hence, it is more effective than traditional design method and can greatly shorten the product innovation cycle.

3.2. Design requirements and test materials
This paper applied reverse design method to perform the innovative design on the new upper clamp model of No. 2 stand. The sample of model was machined and tested. The comparison of the error between the machined sample and the theoretical model indicated that the integration of reverse design and machining technology can realize a high-quality innovative design and improve the appearance and market competitiveness of the product.

4. Conclusion
This study used two different desk lamp stands as its research object, performed characteristic integration innovative design by combining their advantages, and machined and tested the newly designed clamp model. Test results show that the error between the machined sample and the theoretical model was less than 0.02 mm, which can satisfy engineering requirements. In addition, the test also showed high integration degree between reverse design technology and machining technology, which can shorten the product innovation period and improve its market competitiveness, providing great significance for the development of the producer.
Acknowledgements

Thanks for the support of the national treasury of digital manufacturing (CAM) curriculum resources of China (1211911) and 2019 Scientific Research Project of Shaanxi Institute of Technology of China (Gfy19-43) for their financial support.

References

[1] Z. S. Lei, W. K. Yang, Design and Manufacture for a Certain Type of Air Generator Pipe by Reverse Measurement, Aviation Maintenance & Engineering. 04 (2019) 52-53.

[2] C. L. Zhang, J. B. Pan, Reverse Construction of Complex Surface and Five-Axis NC Machining Test, Mechanical Research & Application. 04 (2019) 167-169.

[3] Y. D. Liu, R. R. Zou, Y. Wu, Design of driving lamp shell and mold cooling system based on reverse engineering and conformal cooling channel technology, Manufacturing Technology & Machine Tool, 06 (2019) 176-179.

[4] Lionel Neyton, Pascal Boileau, Laurent Nové-Josserand, et al, Glenoid bone grafting with a reverse design prosthesis, Journal of Shoulder and Elbow Surgery. 03 (2007 (Supplement)) 71-78.

[5] Y. J. Tseng, Y. S. Chen, A Closed-Loop Design Model for Sustainable Manufacturing by Integrating Forward Design and Reverse Design, World Academy of Science, International Scholarly and Scientific Research & Innovation. 07 (2015) 2277-2283.

[6] Y. H. Yang, X.Q. Zhong, Study on reverse design method of industrial design product, Journal of Machine Design. 10(2013) 102-105.

[7] X. Zhao, J. N. Chen, Y. Wang, et al, Reverse design and analysis of rice seedling transplanter with D-shape static trajectory, Transactions of the Chinese Society of Agricultural Engineering. 08 (2012) 92-97.

[8] B. Z. Wang, F. M. Zhang, C. G. Lu, et al, The Research of the Face Shape of the Electric Car Based on Top-Down and Reverse Design, Machinery Design & Manufacture, 02 2018 131-134.

[9] W. M. Li, Z. F. Tang, S. Feng, Research on Model Reconstruction Based on Forward/Reverse Technology, Machine Tool & Hydraulics. 02 (2020) 158-162.

[10] J. C. Weng, W. J. Shi. Research on the reverse modeling and measure technology of the ashtray, Modern Manufacturing Engineering. 12 (2017) 71-77.

[11] X. D. Zhou, S. Y. Cheng, X. R. Yang. Study of Reverse Engineering Technology Oriented to Innovative Design, Machine Tool & Hydraulics. 19 (2015) 25-28.

[12] X. H. Chen, L. Huang, J. F. Lei, et al, Reverse Remodeling Design of Main Reducer Shell for Certain Construction Machinery, Coal Mine Machinery, 03 (2011) 57-60.

[13] T. B. Yu, X. Sun, D. Ha. Structure modeling of artificial bone tissue based on reverse engineering and UG secondary development, Modern Manufacturing Engineering. 03 (2018) 154-159.

[14] D. Liu, Y. Q. Qian, G. F. Yi, et al, The Research of Point Cloud Processing and Fitting Methods in Reverse Engineering, Machinery Design & Manufacture. 03 (2015) 55-57.

[15] Z. L. Song, J. B. Huang, Y.J. Zhang, et al, Analysis on Wear of Sprocket Wheel Using Reverse Engineering Technology, Coal Mine Machinery. 11 (2014) 134-135.

[16] Z. S. Chen, Z. C. Zou, W. L. Liu, Innovative Design of Connecting Rod Based on Reverse Engineering Technology, Mechanical Engineer. 11 (2019) 77-78.