A kind of efficient drilling holes technology modularistically for aircraft beam products

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ABSTRACT

This paper proposes a kind of three-axis automatic drilling-hole equipment for inner flap beam products. The equipment is mounted on a common platform by using a tooling guide rail system to realize the function of automatic drilling-hole. The equipment adopts lightweight design which has compact structure and simplicity of operation, including tooling guide rail system, three-axis motion mechanism, drilling-hole end actuator, control system and software system. In this paper, the design scheme of the equipment is proposed, and the optimum arguments are determined through the experiment of drilling-hole, which ensures the efficiency and quality of drilling-hole, and realizes the automatic drilling-hole of aircraft beam products.

Keywords: Three-axis drilling-hole equipment, Common platform, Beam products, Automatic drilling-hole

1. INTRODUCTION

The structure of aircraft products is complex, with a number of parts and complex coordination relationships, which makes the assembly works account for 50% to 60% of the whole of aircraft manufacturing [1-2]. In the development process of Boeing 777, Boeing 787, A380, F-22 and F-35 and other models, a large number of digital design technology, flexible assembly tooling technology, automatic drilling and riveting technology, digital inspection technology, improved the assembly efficiency of the aircraft greatly, ensure the assembly quality effectively [3-4].

The main function of the aircraft inner flaps is to enhance the lift of the aircraft. The inner flaps move in a backward straight or circular curve around their axis of rotation through a transmission device, which can expand the area and curvature of the wings to achieve the purpose of increasing lift and controlling drag, and to reduce the occurrence of stall, providing greater flexibility and safety for aircraft flight [5]. The front and rear beams are the main load-bearing components of the inner flap structure, and their drilling process is critical for the assembly quality of the flaps. The usage of automatic drilling-hole technology can improve the assembly efficiency and quality of the front and rear beam components of the inner flaps, significantly improving the overall level of aircraft assembly technology, which is of great significance for aircraft assembly [6].

Due to limitations in product structure and production space, the drilling of the front and rear beams of the inner flaps usually requires manual operation. To address this issue, the self-designed three-axis drilling-hole equipment is mounted on a common platform in the paper, using the guide rail on the platform to achieve precise positioning of the equipment, so as to realize the automatic drilling-hole of the front and rear beams, which significantly improves the efficiency, accuracy and quality consistency of drilling-hole. This set of equipment has a compact and lightweight structural design, with simple operation. With just one click of the software button, it can efficiently and high-quality drilling, with low skill requirements for workers. It also improves drilling-hole efficiency, enhances automation coverage, and achieves quality and efficiency improvement in assembly production.

2. STRUCTURE OF THREE-AXIS DRILLING HOLES EQUIPMENT

Automatic drilling-hole technology has the advantages of high precision, great stability, high efficiency, which has been widely used in the field of aviation manufacturing, and gradually replaces of the traditional drilling-hole manually [7]. In order to meet the requirements of aircraft for long life term, high precision and high efficiency, domestic and foreign enterprises have carried out a lot of research on automatic drilling-hole equipment. At present, the universal automatic drilling-hole technology and equipment include: automatic feed drilling technology, flexible guide rail drilling system, crawling robot drilling system.

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(1) Automatic feed drilling technology. In order to solve the problems of unstable quality, low precision and low efficiency of aircraft assembly process, Cooper Company of America, Lubbering Company of Germany and Atlas Copco company of Sweden have all developed automatic feed drilling equipment, which has effectively improved the efficiency of drilling-hole [8].

(2) Flexible guide rail drilling system. In order to meet the requirements for flexible and lightweight equipment in aircraft manufacturing and assembly, Boeing has developed a flexible guide rail drilling-hole system, which can be used to automatically drill holes during fuselage docking. At present, the more mature manufacturers include EI Company and AIT Company of the United States [8]. Beijing Institute of Aeronautical Manufacturing Engineering, Beijing University of Aeronautics and Astronautics, Shanghai Jiao Tong University and Zhejiang University developed flexible drilling-hole equipment to meet the requirements of low-cost and flexible drilling-hole during fuselage assembly [9].

(3) Crawling robot drilling system. In order to meet the flexible requirements of fuselage drilling-hole, the M. Terres company of Spanish has developed a kind of crawling robot drilling equipment with autonomous movement, positioning and high flexibility, which can be used in fuselage docking assembly work [10]. Serra Company, Alema Company and other foreign companies have also developed related equipment. China's Nanjing University of Aeronautics and Astronautics, Beijing University of Aeronautics and Astronautics and Shanghai Aircraft Manufacturing Company have jointly developed a set of crawling robot drilling-hole system [7].

2.1 Overall structure of three-axis drilling-hole equipment

The overall structure of the drilling-hole equipment is shown in Figure 1, which mainly includes tooling guide rail system, three-axis motion mechanism, drilling-hole end actuator, equipment control system and software system. The drilling-hole posture is in a horizontal machining form, with four products to be processed arranged side by side on a universal platform. The three-axis drilling-hole equipment is installed on a universal platform through a base, with automatically movement of the X/Y/Z directions of the platform. The drilling-hole end actuator of the equipment can automatically drill holes along the X/Y direction of the universal platform.

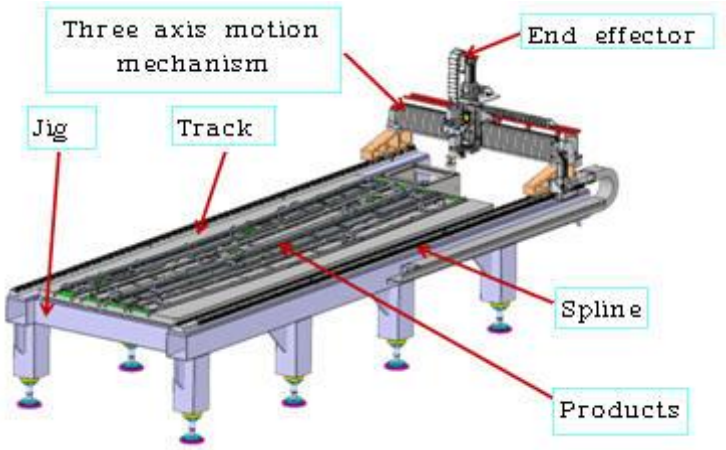

Figure 1. Overall structure of drilling-hole equipment

2.2 Tooling guide rail system

The tooling guide rail system that is shown in the figure 2 provides a solid support foundation for the equipment, allowing the drilling equipment to freely move to any position in the X-axis direction for drilling. The connection between the drilling-hole equipment and the tooling guide rail system is equipped with components such as X-axis gears, reducers, motors, drives, drag chains, and bases. One side of the main guide rail is equipped with X-axis racks, which adopt an X-axis rack-gear transmission system to enable the equipment to move throughout the entire X-axis travel.

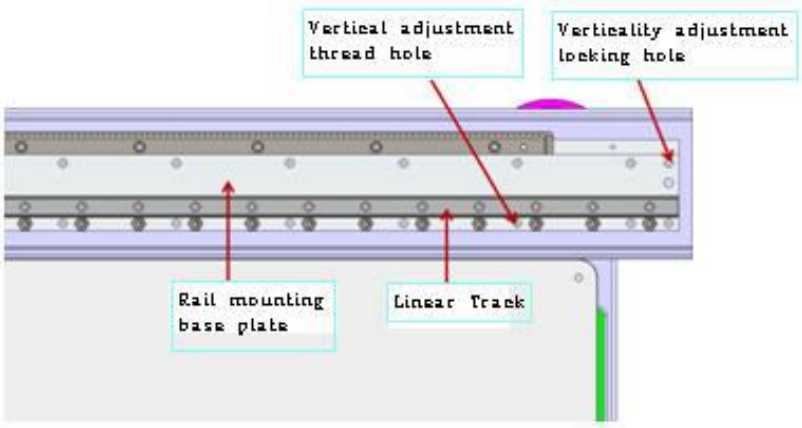

Figure 2. Structure diagram of tooling guide rail system

2.3 XYZ three-axis motion mechanism

XYZ three-axis motion mechanism is shown in Figure 3, which is mainly composed of equipment base, auxiliary side base, X-axis rack-gear drive parts and base, X-axis linear guide rail slide block combination, etc. The motion system of three axes including X/Y/Z in the mechanism are all composed of high-precision linear modules to ensure the accuracy of hole position when drilling holes. The main function of the XYZ three-axis motion mechanism is to realize the horizontal movement of the end actuator in the travel range of the hole. The X-axis is the feed in the length direction of the work piece, and the Y-axis is the feed in the width direction of the work piece. Along the Y-axis, the product can be arranged in four side by side, and the travel of the Y-axis is about 900mm. The guide slide block is connected by the bracket and the Z-axis base mounting plate to enhance the bending stiffness of the Z-axis base. The Z-axis is the feed in the direction of the thickness of the work piece and provides the mounting base for the end actuator of the drilling holes.

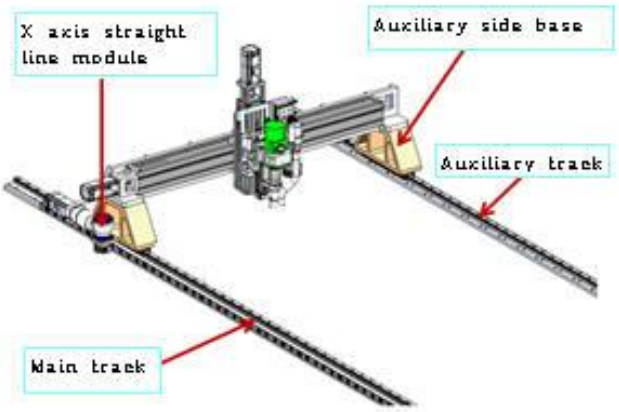

Figure 3. XYZ three-axis motion mechanisms

2.4 Drilling-hole end actuator

The drilling-hole end actuator mounted on the XYZ three-axis motion mechanism, as shown in Figure 4, is a key component of the three-axis automatic drilling-hole equipment. It includes core modules such as a pneumatic spindle, a dust suction module, a vision module, a feed cylinder, a chip removal pipe and an end base. This drilling-hole end actuator integrates functional modules such as visual positioning based on datum hole, cutting tool cooling and lubrication, and automatic chip removal, to achieve efficient drilling. Compared with traditional electric spindles, the drilling-hole end actuator adopts a pneumatic spindle with continuously variable transmission, which reduces the overall weight and volume, and has the characteristics of safety, explosion-proof, easy operation, and long service life. At the same time, the maintenance cost is also lower.

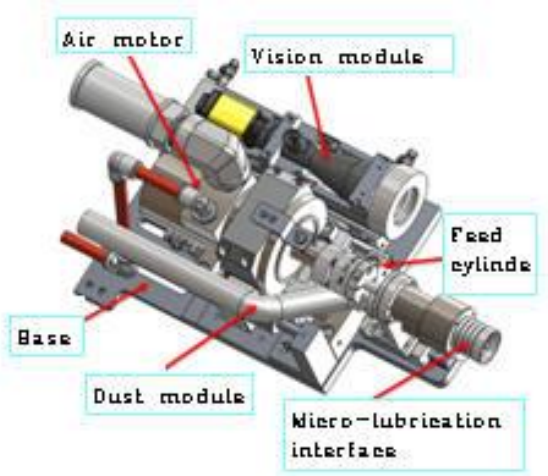

Figure 4. Drill hole end effectors

2.5 Equipment control system

The automatic drilling-hole equipment control system is mainly composed of integrated management software system, KEBA motion control system, HM interaction, and detection and display unit. Other functional modules include intelligent camera vision module, ultra-low temperature oil mist cooling and lubrication module, chip suction unit module, spindle speed measurement module, etc. The composition of the control system and communication principle is shown in Figure 5.

Figure 5. Composition of the control system and communication principle

2.6 Software system

The software system for automatic drilling-hole equipment is composed of off-line programming and simulation software, and integrated process management software. The offline programming and simulation software of this system running on high-performance graphics workstation, based on the secondary development of CATIA/DELMIA, extracts point information from the work piece model through interactive operation with CATIA/DELMIA. Then the software generates and sequences paths based on requirements of user, and after compensating by datum holes to generate program codes that can be processed by the equipment. According to the generated program code, automatic simulation and collision detection are implemented in the DELMIA environment.

Integrated process management software running on the upper computer is the control center of automatic drilling holes process, according to the processing program, which can send instructions to the equipment, and realize the functions of taking photos, position compensation and drilling. The software can display real-time processing related process arguments and equipment status, and operators can modify corresponding process arguments or change equipment

arguments through the software. It also provides the database storage function, which can collect and store the processing data and operation to the database in real time.

3. DRILLING-HOLE PROCESS AND PROCESS ARGUMENTS

Automatic drilling holes process of three-axis drilling-hole equipment is as follows:

(1) Equipment self inspection and initialization, equipment calibration by the cutting tool calibration table (equipment returns to zero), cutting tool test on the tool testing board, manually inspection of the quality of the hole, and then starting of drilling -hole on work piece after confirmation of qualification;

(2) Before drilling-hole the equipment will detect the position of each datum hole based on the hole coordinates generated by offline programming and simulation software, with the assistance of a camera, and previously walk through all points that need to be processed to check the accessibility of the equipment end actuator and the approximate position of the hole. After completing to walk through all the points that need to be processed, the equipment starts drilling hole;

(3) The processing subroutine controls the end actuator to complete the processing of holes of the same diameter at this station according to the sequence and arguments set by the program. The specific process is as: after processing the datum hole detection results by the control system, the end actuator is controlled to move to the front of the hole to be drilled on the part, the pneumatic spindle starts to rotate forward, and the feed cylinder uniformly drives the pneumatic spindle to complete feed drilling-hole by the speed stabilizer. When the cutting tool extends out of the other side of the work piece, the pneumatic spindle stays for a short time and returns to zero subsequently. Then the end actuator will move immediately to another hole for processing until the processing of all holes on the work piece is completed;

(4) The above processes will be repeated to complete the processing of other holes of the same diameter at this station in turn until completing the processing of all holes set by program at this station.

In order to obtain the optimal drilling-hole process arguments, four groups of different process arguments were tested on the test plate. Finally it was determined that the optimal drilling-hole arguments for the laminated plate with 3mm thick 7050-T7451 material and 1.6-2mm thick 2024-T3 material is as table 1.

Table 1. Drilling-hole process argument

Material	**Thickness**	**Drilling speed**	**Feed speed**
7050-T7451 &2024-T3 lamination	4.6 ~ 5mm	3500rpm	100mm/min

4. CONCLUSION

4.1 Conclusion 1

The three-axis drilling-hole equipment for the product of beam type integrates datum hole visual positioning, cutting tool cooling and lubrication, automatic chip removal and other automatic drilling-hole functions. This set of equipment is flexible in layout and easy to operate. With just one click of the software button, it can efficiently and high-quality drilling. With the click of a button on the software, the equipment can drill efficiently and accurately, which significantly improving the efficiency, accuracy and quality consistency of the drilling, and achieving the quality and efficiency of assembly production.

4.2 Conclusion 2

Through the test, a set of reliable equipment automatic drilling-hole arguments was determined and solidified, which reducing product quality issues caused by the manual operation of non-standard, improper location of drilling jig, errors of tool using ,etc.

4.3 Conclusion 3

Through experimental verification, the automatic drilling-hole equipment can meet the requirements in aspects of drilling-hole quality and stability, which can be widely used in product production.

Further work will study the application of this drilling-hole equipment in the efficient drilling holes of other aircraft products such as rib parts, and develop research in the direction of more automation.

REFERENCES

[1] XU Guokang, "Automatic assembly technology for large aircraft", Acta Aeronautica et Astronautic Sinica, 29(3):734-740,2008.

[2] Lauterbach K L. Henker R, Junker M, et al. "High resolution spectroscopy on optical signals in fiber communication systems//Photonics and Microsystems", 2008 International Students and Young Scientists Workshop. IEEE, 2008: 36-38.

[3] Butterfield J, Crosby S, Curran R, et al. "Optimization of aircraft fuselage assembly process using digital manufacturing", Journal of Computing and Information Science in Engineering, 2007(7):269-275,2007.

[4] CHEN shumin, ZHANG Haibao, et al. "Application of digital assembly technology and process equipment in large aircraft development", Aeronautical Manufacturing Technology, 2015(8):31-37,2015.

[5] WANG Chunyan, "Structural Analysis and Assembly Design of Flap of an Aircraft", China Science and Technology Information, 2023(14):38-41,2023.

[6] CHEN Shuai, Liu Xule, Chen Lei, "A compact end-effector for Aircraft Mounting Holes", Modern Manufacturing Technology and Equipment, 59(04):80-82,2023.

[7] WANG Min, WANG Xiemiao, CHEN Wenliang, "Automatic mobile drilling mechanism with metamorphic function", Journal of Beijing University of Aeronautics and Astronautics, 41(3):398-404,2015.

[8] Boeing Co. Flexible guide rail drilling machine, US6843328 ,2015-01-18.

[9] ZHU W D, MEI B, KE Y L, "Inverse kinematics solution of a new circumferential drilling machine for aircraft assembly", Robotica, 34(1):98-117, 2016.

[10] Marguet B, Cibiel C, "Crawler robots for drilling and fastener installation", an innovative breakthrough in aerospace automation, SAE, 2008:2292.