Research on automatic assembly technology for final assembly of helicopter fuselage

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Abstract. The helicopter fuselage has the characteristics of compact structure space, complex coordination relationship and weak rigidity, etc. It is difficult to control the accuracy of the desired shape. According to the high precision and quality requirement of final assembly for helicopter fuselage, the application status of automatic assembly technology in aviation manufacturing was analyzed. Then the difficulties of automatic assembly technology for fuselage final assembly were also discussed. In this paper, an automatic assembly system for the final assembly of helicopter fuselage was designed, and relevant key technologies of the assembly system mentioned above were proposed. The designed system have the functions of automatic positioning, clamping, measuring, drilling, feeding and blind fastener riveting for fuselage components, which can improve the assembly quality and efficiency of helicopter fuselage during the final assembly process.

1. Introduction

In aircraft manufacturing, due to the large size, complex shape, and the large amount of parts and fasteners, the workload of aircraft assembly accounts for about half or more of the total workload [1,2]. Automatic assembly technology represents for the development trend of aircraft manufacturing technology, and it is also one of the key solutions to improve the quality and efficiency of aircraft assembly and to ensure the long life of aircraft [3,4]. In the aviation enterprises of China, to the fixed-wing aircraft manufacturers, they have developed the research and application of automatic assembly technology and equipment, such as (1) automatic drilling[5,6], (2) automatic riveting of panels[7-9], (3) automatic assembly of components[10,11], (4) automatic docking of large components [12] and so on. Compared with fixed-wing aircraft, helicopter assembly still adopts traditional manual assembly methods, i.e. the positioning and clamping components with a large number of complex rigid toolings. Automatic assembly, which having a huge influence on the assembly quality and efficiency of helicopter fuselage, is basically in a blank state.

Due to the internal structure of helicopter is compact, and the coordination relationship is very complicated. During the assembly process of fuselage structure, the positioning and clamping of product components, drilling and fastening, especially for the riveting of blind fasteners, are the key factors to ensure the assembly quality and efficiency. In the actual assembly site, the accuracy of positioning and clamping has a direct relationship with the position accuracy and shape accuracy of fuselage structure. And the quality of drilling affects the long life of the fuselage. In addition, the amount of blind fasteners is huge (for example, there are about 12000 blind fasteners in AC352 helicopter fuselage structure). Some problems, such as unstable quality and low efficiency, often
occurred in manual drilling and riveting. Aiming at the existing problems in the final assembly process for helicopter fuselage, firstly, the key technologies of automatic assembly of helicopter fuselage final assembly were studied, and then an automatic assembly system for final assembly of helicopter fuselage was designed. The system has the function of automatic positioning, clamping, measuring, drilling, feeding and fastener riveting of fuselage components. Finally, the assembly quality and efficiency of helicopter fuselage final assembly was improved.

2. Application status of automatic assembly technology
Automatic assembly technology is widely used in the field of foreign aviation manufacturing, especially in the assembly of large fixed-wing aircraft. B & C company, Italy, provided automatic assembly lines to Boeing and Airbus for the assembly of B787 and A380 fuselage sections. Four automatic assembly lines, which including robotic riveting system, are constructed for the 44th and 46th sections of B787 Dreamliner. As shown in figure 1, the robotic riveting system includes two sets of robotic systems, i.e. external robotic system and internal robotic system. The two systems work together to achieve the automatic drilling and the lock bolt riveting of composite fuselage panel. It is mentioned that, the external robotic system is responsible for automatic measuring, clamping, posture adjustment, drilling and countersinking, absorption, sealant application and bolt inserting, while the internal robot system is responsible for automatic clamping, absorption, collar installation, riveting, and etc.

![Figure 1. Robot automatic riveting system of B787 fuselage section.](image)

Comparing with the aircraft with fixed-wing, helicopter airframe has smaller size and tight operating space. As a result, it is very difficult to apply automatic assembly equipment or tooling, because they often have a large size. In recent years, with the development of manufacturing technology, the automatic and digital assembly technology in the whole industry, is becoming more and more mature for helicopters. Relevant technologies and equipment are developed in some famous aircraft companies, such as Airbus, Bell and Sikorsky, and they have been widely used in the assembly process of helicopter body parts and subsystems.

As shown in figure 2, the robot automatic assembly system of a helicopter fuselage assembly in Airbus Helicopter Company is introduced. The system clamps and locates the fuselage structure with a set of automatic positioning tooling. The automatic assembly of the new helicopter fuselage structure is developed by digital measurement, precise positioning of the robot, automatic drilling and riveting and other technologies. With the system, the total assembly time is less than 28 hours. And the system can improve the assembly quality and efficiency of fuselage structure greatly. Obviously, the high performance demands of helicopter structure can be fulfilled.
3. Technical Characteristics of Automatic Assembly System for Final Assembly

The structural characteristics for final assembly of helicopter fuselage can be summarized as follows:
1) the fuselage has a cylindrical structure, and the assembly working area has a circumferential distribution; 2) the fuselage also has a weak rigidity, correspondingly, it requires maintaining the required shape that defined by the official assembly documents in the assembly process. While, to the riveting system that working with an automatic robot, it has the following characteristics, as shown in figure 3.
Firstly, with the view of structural form, it carries the end-effector to work.
Secondly, due to the structure limitations, the working scope of the robot is limited in a certain space comparing with the whole fuselage.
Thirdly, the positioning accuracy of the robot is not high enough.

Due to the characteristics of the above technologies, in this paper, the automatic assembly system for final assembly of helicopter fuselage is mainly composed of (1) rotary positioning tooling system, and (2) robot automatic riveting system. To the robot riveting system, it includes three main parts, i.e. 1) the 7th axis mobile platform, 2) the robot, and 3) the end-effector. The above system is mounted on the 7th axis mobile platform with the end-effector to be a whole tooling unit. With the linear motion of the 7th axis, and the rotation driven by the rotary tooling, the working limitation of the robot can be compensated effectively.
There are four hinge joints for main reducer on the fuselage, with which the rotary positioning tooling system locating and clamping the helicopter fuselage. Consequently, during the rotating process, the tooling system positions the fuselage structure, and the pneumatic shape was also controlled to the desired requirement. It is mentioned that the working space of robot riveting system is limited, which can only cover a quarter of turn the fuselage structure. However, with the help of rotary tooling, the remaining there quarters of assembly area for the fuselage structure can be completed. To the rotating tooling system, it carries the fuselage body component rotating 90 degree at one time. And with the help of the robot riveting system, the riveting of the current assembly area can be accomplished. In other words, the assembly of the whole body circumference can be completed for four rotations of the tooling system.
Based on the structure of the assembly system, the main work flow of the system can be described as follows.
1) After the pre-assembly work of front fuselage, mid fuselage and transitional section is completed, the digital rotating flexible tooling is designed to locate and clamp the fuselage structure automatically.
2) The robot carrying the end-effector moves linearly through the 7th mobile platform, to the position of the riveting station.
3) Then with the help of photographic measurement unit mounting on the end-effector, the datum holes in the fuselage structure can be measured, and coordinate system between the workpiece and robot riveting system can be kept in a harmonious status.
4) The robot riveting system moves to the first assembly point, to perform the operations including automatic drilling, feeding and blind fasteners riveting.
5) After that, the system moves to the next point to drill and rivet, and recycles this operation until the assembly operations are completed in the concerned area.
6) The rotary tooling system drives the body structure to rotate, and then robot riveting system starts the following assembly work, and it will recycle it until the assembly operation of the whole body is completed.

4. Key Technology during Automatic Assembly

Automatic assembly technology of helicopter fuselage final assembly covers tooling technology, robotics technology, measuring technology, drilling and riveting technology, and integrated control technology, etc. It covers a wide range of majors, and it is also difficult to achieve. The following key technologies need to break through.

4.1. Automatic positioning for fuselage final assembly

According to the characteristics of helicopter fuselage structure, the positioning modes of linear motion tooling and circumferential motion tooling are compared and analyzed, and a form of rotating automatic positioning tooling with circumferential motion is defined. As shown in figure 4, the tooling includes the main frame of the tooling, rotating mechanism, modular positioner and modular sustaining mechanism, so as to complete the automatic rotating, positioning and shape controlling of helicopter fuselage section.

Figure 4. Rotary positioning tooling for fuselage structure.

In order to realize the automatic positioning of helicopter fuselage structure, the structure needs to be designed for the automatic positioning[13]: 1) In order to enhance the rigidity of the fuselage structure at the breakdown interface and reduce the deformation of the fuselage during the positioning process, the production breakdown interface is necessary to be optimal designed[14,15]. 2) To facilitate the rapid connection between the fuselage structure and the fixture, and shorten the installation and position time of the fuselage, the hinge joints of the fuselage, which matching with the modular positioner of rotary tooling, also need to be designed. 3) To the design and layout of the measuring datum points (holes), they should be set in the rigid area of the fuselage as far as possible and distributed uniformly, and then they would envelop the fuselage in a wide range so as to improve the positioning accuracy of the riveting system and products.

The main frame of the tooling is consisted of four basing pillars, and a set of annular structure. To facilitate product to enter and exit with good convenience, the annular device is divided into two arc portions, i.e. the upper and lower. The rotating mechanism includes the main structure and the driving
mechanism. The driving motors and gears are installed together with the main structure. Because the double drives move synchronously, so it can drive the product rolling. To the modular positioner, it includes base mechanism, lifting drives, positioning and connecting structure, process joints, and other parts. The positioner could connect with the fuselage structure quickly to lift and position the product. Besides, the modular sustaining mechanism is joined with the product to help control the shape of the body during the rotating motion.

After the pre-assembly optimization of the integral helicopter fuselage is completed, the fuselage structure then is carried to a required assembly position, i.e. the position that connecting the main hinge joints of the fuselage, with a special carriage. After the modular positioner is joined with the fuselage structure, the product can be lift and clamped to the desired position. It is mentioned that the modular sustaining mechanism clamps the fuselage to maintain the shape of the aircraft. And the rotating mechanism drives the fuselage to rotate until to the working position, then the assembly operations of the robot automatic riveting system can be carried out.

4.2. End-effector design for automatic drilling and blind fastener riveting

For composite structure airframe, drilling and blind fastener riveting are the key assembly process. The technology of end-effector of automatic drilling and blind fastener riveting is matured abroad[16], and has been applied in the assembly of helicopter fuselage, composite wing, and other components. At present, there are some preliminary applications of automatic drilling in China, but the automation of blind fastener riveting is still in the research status, and has not been applied in aircraft manufacture.

To the end-effector technology which integrates automatic drilling and blind fastener riveting, there are many difficulties. Such as, 1) the structure of the end-effector is complex, and the transposition form of each functional unit is hard to determined; 2) the blind fastener has a slender structure, which makes it difficult to design the structure of automatic feeding unit; 3) the design of the blind fastener riveting unit is compact, due to the narrow space of the product, 4) the integration and control of the end-effector with the clamping, photographic measurement, drilling, feeding, blind fastener riveting, absorption, posture adjustment and other functional units.

As shown in figure 5, the end-effector of automatic drilling and blind fastener riveting includes photographic measurement unit, clamping mechanism, automatic drilling unit, feeding unit, automatic sealing unit, blind bolt riveting unit, posture adjusting unit and etc. It has the functions of automatic positioning with product’s feature, posture adjustment, clamping, drilling and countersinking, feeding, automatic sealing, riveting, etc., which can assemble the helicopter fuselage structure automatically.

4.3. Precise adjustment of position and posture of automatic riveting system with digital measurement

Accurate control and adjustment of robot riveting position and pose based on digital measurement technology, is the important solutions of high precision assembly of helicopter fuselage structure. The main technical difficulties can be summarized as follows: 1) the establishment of the relative position relationship of fuselage structure, tooling and robot, with the help of photogrammetric measurement, and precise adjustment of the holes’ position. 2) The accurate adjustment of the position and the pose of the robot, based on skin surface vector measurement of drilling and riveting.

4.3.1. Accurate positioning technology of robot automatic riveting base on on-site measurement. The
datum holes in the fuselage structure are photographically measured and the coordinate system of the fuselage is aligned to determine the actual position of the robot automatic riveting. Its working process can be described as follows: firstly, the control system sends image acquisition command through Ethernet, and then opens the light source. Secondly, the CCD camera begins to take the image of the datum holes of the part. By calculating and analyzing the image of the datum holes, the information of the datum hole is obtained. With the visual algorithm, the position deviation between the axis of the positioning hole and the theoretical coordinate can be calculated, and then the data would be fed back to the control system. Therefore, the automatic riveting system is positioned for another time to ensure the holes’ vector before drilling. The above principle can be explanation with figure 6.

4.3.2. Accurate adjustment technology of automatic riveting posture base on laser measurement of surface vector. The multi-point laser rangefinders are used to calculate the vector of the riveting point synchronously, and then the posture of the riveting end-effector is adjusted. As shown in figure 7, four laser rangefinders are designed and installed in the clamping mechanism of the end-effector in this system. The rangefinder emits laser and receives reflected signal, then calculates the linear distance synchronously. According to the distance data of the four rangefinders, the vector of the skin at the holes’ position can be approximately fitted. The automatic riveting system adjusts the drilling and riveting posture accurately according to the vector data.

4.4. Multi-system integration for automatic assembly of fuselage structure
Data from off-line programming system is imported by computer integrated control[17,18]. According to process parameters, the cycle control of the end-effector and the positioning control of the drilling robot can be executed as planned. In detail, to fulfill the requirements of automatic assembly, the cycle control contains coordinated control of feeding system, photographic measurement of datum hole, on-site visual surveillance and so on.
There are many subsystems in the control system of automatic assembly system. While, there is also measurement information. During the above integration process, the KRC4 controller of the robot itself is used for the robot control, the control module of Kollmorgen is used for the rotary tooling control, and the end-effector is controlled by the other CNC system. It is necessary to build a platform to achieve the information exchange and coordinated control between different working systems. The system of the paper uses integrated control software of the host computer to achieve the functions above. The integrated control software of host computer communicates with other units in the system through the form of Ethernet communication, and then the control and sequence, measurement and security protection of each sub-unit can be in a harmony status. As shown in figure 8, by the feedback of various information, the host computer judges whether the robot and the end-effector are running according to the orders sent from itself or not, and whether they are in the correct place or not. The host computer also manages the data such as measurement data, process parameters, and alarm records, and so on.

The automatic assembly system of fuselage final assembly is controlled by integrated software. The integrated software coordinates the control sequence of each system according to the process flow. The software receives the data of drilling and riveting position from off-line programming system, and then with which it completes the cycle control of drilling and riveting, and manages and records the parameters, as shown in figure 9.
Figure 9. Integrated control flow of automatic assembly system.

5. Conclusion
According to the characteristics of helicopter fuselage structure and the requirement of assembly with high precision and high quality, relevant key technologies, such as, (1) automatic positioning tooling for helicopter fuselage final assembly, (2) automatic riveting end-effector for blind fasteners, (3) precise adjustment of position and posture during riveting process, and (4) multi-system integration are studied. Finally, the automatic assembly system for final assembly of helicopter fuselage is designed in this paper.

To the automatic assembly system for final assembly of helicopter fuselage, it has the characteristics of flexibility, digitalization and modularization, and which can complete the function of automatic positioning, clamping, measuring, drilling, feeding and riveting of blind fasteners of fuselage components and so on. In order to achieve the engineering application of the system in the production of helicopter fuselage final assembly as soon as possible, a large number of process tests should be done to optimize and improve the maturity of the system.

6. References
[1] Zou J H, Riaz A H and Fan Y Q 2006 Research for major-parts digital assembly system of large-scale airplane Wseas International Conference on Circuits pp 337–43
[2] Wu D W and Yuan J C 2012 Based on flexible automation fixture of siding components of assembly craft planning and simulation Applied Mechanics and Materials 224 pp109-12
[3] Sun W 2013 A laser tracking-vision guiding measurement system for large-scale parts assembly Advanced Materials Research 718-720 pp 868-74
[4] Gitta M 2013 Destination Myachkovo Airport (Los Angeles: Sent Publishing)
[5] Jin L, Shi X and Dong H Y 2014 Study on robot automatic drilling of carbon fiber reinforced plastics (CFRP) Advanced Materials Research 889-890 pp1144-9
[6] Bi Y B, Li Y C and Jiang Y H 2013 An industrial robot based drilling system for aircraft structures Applied Mechanics and Materials 433-435 p7
[7] Lin H C 2007 An internet-based automatic riveting system using remote monitoring and control IEEE International Conference on Systems
[8] Feng J 2017 Design of the control system for automatic riveting machine based on PLC International Conference on Robots & Intelligent System

[9] Jiang L P, Chen W L and Wang M 2014 Approach to interference aircraft automatic riveting process control of drilling and riveting Transactions of Nanjing University of Aeronautics & Astronautics 31(6) pp 609-14

[10] Zhen M and Jing 2011 Automatic assembly for combined mold components based on SolidWorks International Conference on Electronics

[11] Zhang H, Guo H J and Zhang S S 2014 Manufacture of flexible automatic assembly platform for aircraft component level Applied Mechanics & Materials 635-637 pp 1857-60

[12] Lang Y D, Yao Y X and Xia P J 2008 Research on exact placement technology of virtual assembly for large-scale products Applied Mechanics & Materials 10-12 pp 460-5

[13] Shpitalni M, Elber G and Lenz E 1989 Automatic assembly of three-dimensional structures via connectivity graphs CIRP Annals - Manufacturing Technology 38 (1) pp 25-8

[14] Jin Y, Abella R and Ares E 2013 Modeling and digital tool development of a new similarity metric for aerospace production International journal of advanced manufacturing technology 69(10) pp 1-4

[15] Padillo A, Racero J, Oliva M and Mas F 2017 Design and implementation of a prototype for information exchange in digital manufacturing processes in aerospace industry Product lifecycle management

[16] Bullen and George N 2013 Automated/mechanized drilling and countersinking of airframes (Warrendale: SAE International Press)

[17] Aehnelt M and Bader S 2014 Tracking assembly processes and providing assistance in smart factories Icaart pp 161-8

[18] Campos A, Johnson R and Kennedy J 2016 System and method for wiring an aircraft (US Patent: 2016004863)

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