Development of Mechatronic Assembly Equipment for Assembling Internal Structural Components of Large Commercial Aircraft Using Laser Positioning System Instead of Jigs & Tools

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Mitsubishi Heavy Industries, Ltd. (MHI) is facing price competition for large commercial aircraft fuselage panels, which are the main products of its aircraft business, between OEM customers Boeing and Airbus, in addition to a severe business environment due to price competition with Tier 1 manufacturing competitors. Against this background, we need to build a manufacturing and production system that can quickly follow production fluctuations and cost reductions. As a means to solve this issue, we reviewed the production method that relies on many large stationary jigs and tools operated mainly by skilled workers and worked on the development of automatic assembly equipment using industrial robots that have production flexibility and enable labor saving. This report introduces the newly developed robotized assembly equipment for fuselage panel internal skeleton subassemblies.

1. Development background and features of robotized assembly equipment

1.1 Characteristics of products

MHI has been producing fuselage panel-shaped parts that are longitudinally and circumferentially divided from the rear fuselage of civilian aircraft as shown in **Figure 1**. The fuselage panel has a structure in which internal skeleton parts are assembled on the outer plate, which is thin and has low rigidity, to reinforce it in order to maintain the shape and strength. **Figure 2** presents a model of the fuselage panel structure. The internal skeleton parts include components with different shapes and sizes. In particular, the strength members to be positioned longitudinally in the airframe are as long as 8 m. This longitudinal strength member, called a stringer, is attached to the frame, which is a circumferential strength member, with a clip and the required assembly accuracy is as strict as ±0.8 mm or less. In addition, there are as many as 260 and 950 types of stringers and clips, respectively.

In the current production process, assembly is performed using a large stationary jig and tool as shown in **Figure 3** and combining it with small positioning jigs and tools to match the shape of the airframe. However, large stationary jigs and tools have low versatility and each time the design is changed, the jigs and tools need to be modified or newly made, which result in high costs. There is also a problem in terms of the quality not being stable due to differences in assembly accuracy resulting from positioning, drilling and riveting work depending on the proficiency level of the workers. One of the methods to suppress quality variations caused by workers is the automation of drilling and riveting with automatic riveters, which are suitable for drilling and riveting outer panels without obstacles. For internal skeleton parts, however, this method results in interference with parts and cannot be used. Therefore, we have started to develop an automatic machine aiming at the miniaturization of the equipment, applicability to different parts with various shapes and high-precision assembly.

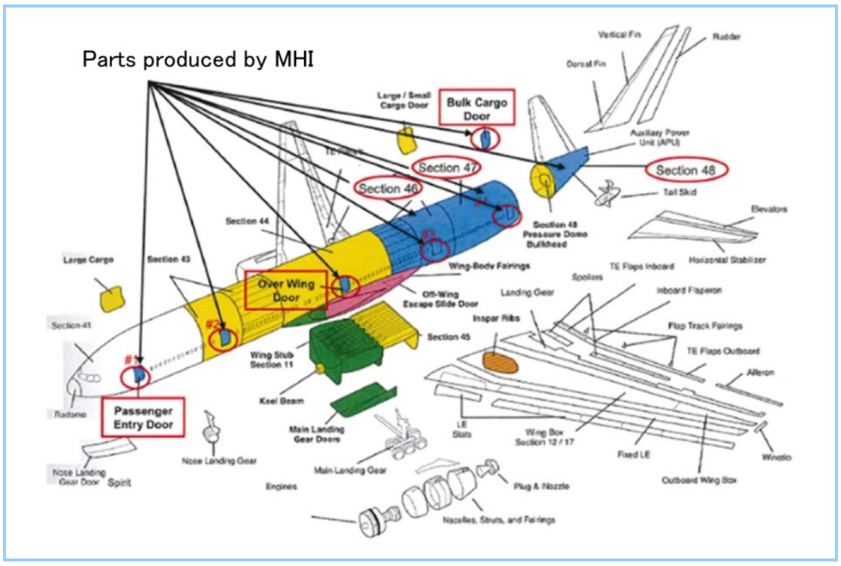

Figure 1　MHI's production scope

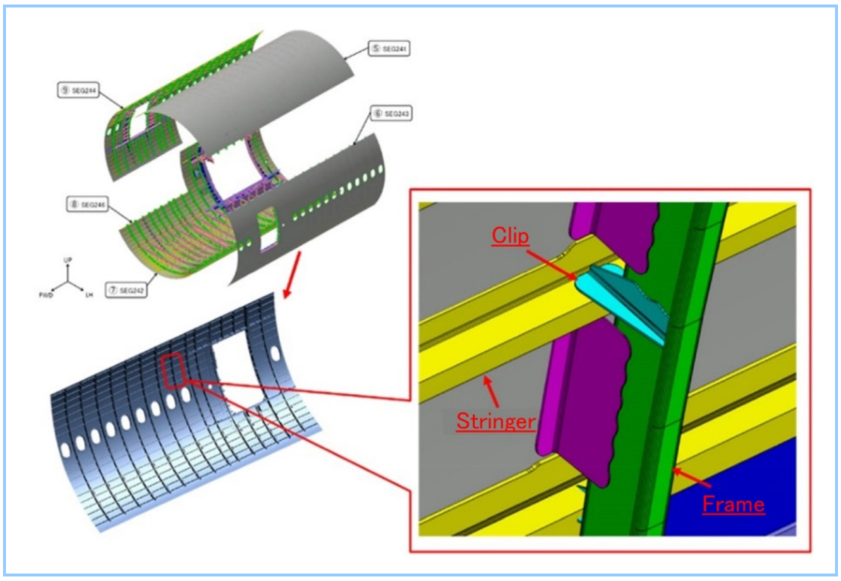

Figure 2　Fuselage panel structure

Figure 3　Assembly using large stationary jig

1.2　Requirements for assembly equipment and concepts for satisfying them

The basic policy for the development of new assembly equipment is to break away from dependence on skilled workers, save labor and improve flexibility by eliminating large stationary jigs and tools. Based on this, we have developed robotized assembly equipment with the following concepts.

(1) Shape retention and handling of long-length and low-rigidity parts peculiar to assembly of commercial aircraft structures
(2) Highly-accurate positioning of clips to stringers
(3) Small end effector that enables approach to narrow processing areas
(4) Identification system for small fasteners in small quantities and various types

2. Specifications of robotized assembly equipment

Figure 4 illustrates the configuration of the robotized assembly equipment. **Figure 5** briefly depicts the sequence of this equipment.

This equipment has four main features. These features are described below.

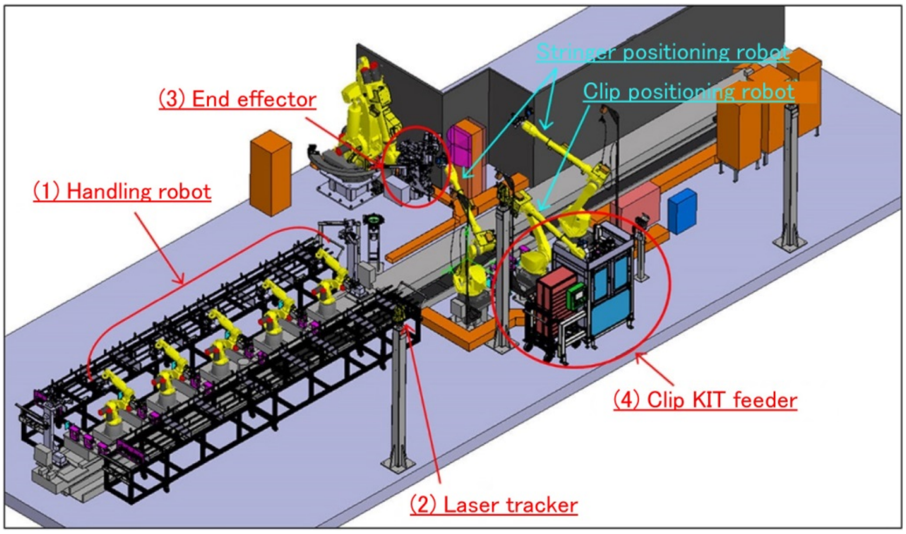

Figure 4 Schematic of robotized assembly equipment

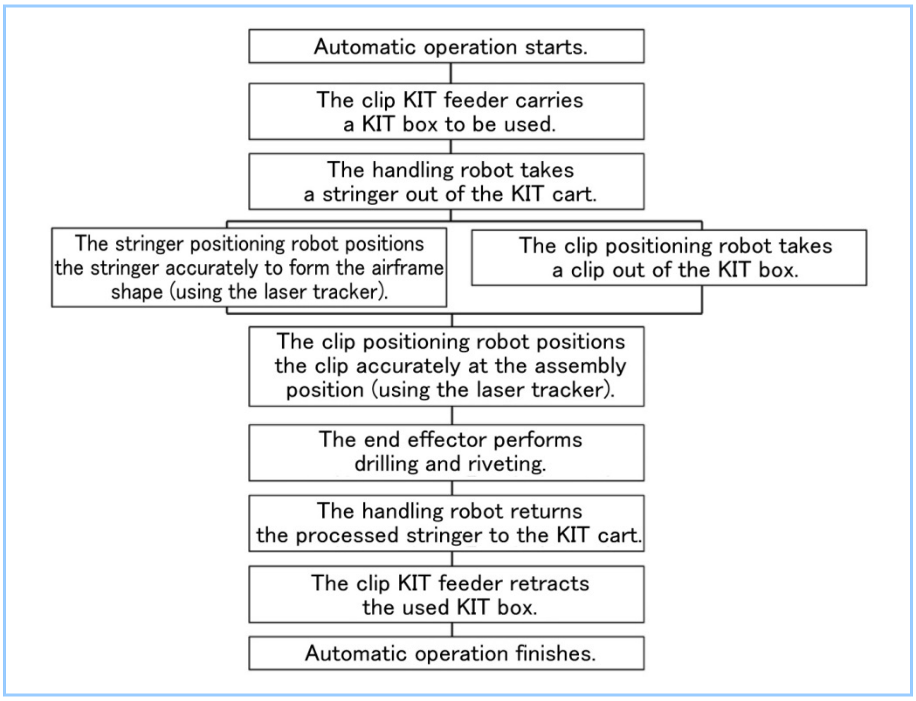

Figure 5 Operating sequence of robotic assembly equipment

2.1 Robotized handling

The handling of long-length, low-rigidity stringers with singly- or multiply-curved surfaces is performed using up to five robots. A link motion in which four slave robots trace the motion of one master robot is applied. This makes it possible to handle long-length stringers using multiple robots. Program creation is also simplified because it is only necessary to create a program and execute teaching for the master robot.

Each handling robot operates within its repetitive positioning accuracy. However, the robot repetitive positioning accuracy cannot satisfy the required accuracy for assembling the aircraft structure. In addition, each part bends due to its own weight in areas other than the vicinity held by the robot, causing a mismatch with the shape on the 3D model. Therefore, there are two stringer positioning robots for correcting the deflection of a stringer. The gripping positions of the stringer positioning robots and the gripping positions of the clip positioning robot are monitored by measurement with a laser tracker and corrected to the spatial position defined according to the 3D model. This enables assembly at a clip installation position with a highly-accurate relative position between the clip and the stringer.

2.2 Correction with laser tracker

Conventional 6-axis robots feature a high "repetitive position accuracy," which is the accuracy of moving to the position once taught, but have a low "absolute position accuracy," which is the accuracy of positioning to the position specified by the coordinates, due to backlash of the gears of each axis, change over the years caused by gear wear, changes in end load, etc. As a measure to deal with this issue, we have developed and applied to this equipment a mechanism that measures the end position of the robot's end effector using a laser tracker and controls the measured value through feedback. As a result, this equipment can meet the stringent requirements of assembly accuracy of ±0.8 mm or less. This equipment accurately positions a total of three robots— the two stringer positioning robots and the one clip positioning robot described in Section 2.1—and uses three laser trackers. Since the three laser trackers need to share coordinates within the equipment, we have also developed a mechanism to share their measurement results. This makes it possible for laser trackers to perform measurement in parallel, leading to a reduction in cycle time. With these mechanisms, robotized assembly makes it possible to achieve accuracy at a level three times higher than the current work executing method using conventional large stationary jigs and tools.

2.3 Development of end effector

Figure 6 shows a stringer and clips to be processed. Both parts have a special shape to maintain strength and reduce weight and there are almost no simple planes. Furthermore, since handling robots and positioning robots exist densely near the processing point, the shape and size of the end effector need to ensure that approaching the narrow processing area is possible.

Accordingly, we have developed an end effector that can approach narrow processing areas as shown in **Figure 7**. End effectors are inevitably heavy due to their necessary functions, but we have enabled movement and posture that makes the most of the degree of freedom, by keeping the weight within the payload range of large robots. In addition, by minimizing the components that approach the processing point such as downsizing the pressure foot that clamps the stringer and clip during processing and using a mechanism that retracts the drilling spindle and the riveting anvil when approaching the processing point, it becomes possible to approach narrow areas. At the same time, in order to meet the strict process requirements of aircraft such as deburring that always occurs in the case of hand work, we have also developed a drill that suppresses the occurrence of burrs and have set machining conditions that achieve high-quality drilling and a shorter cycle time.

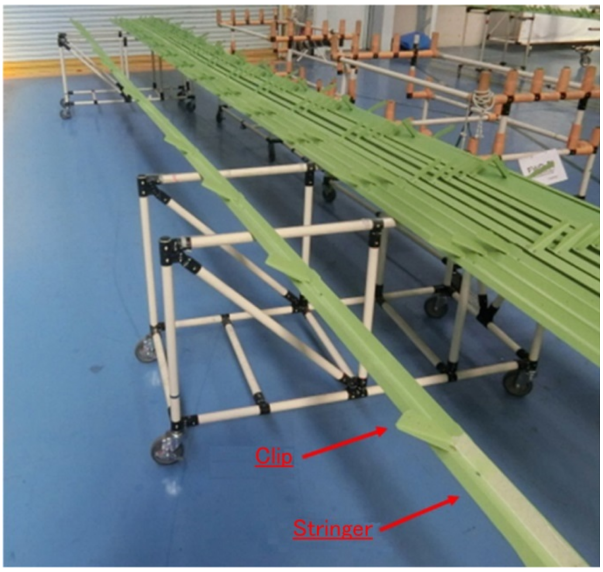

Figure 6 Process target parts

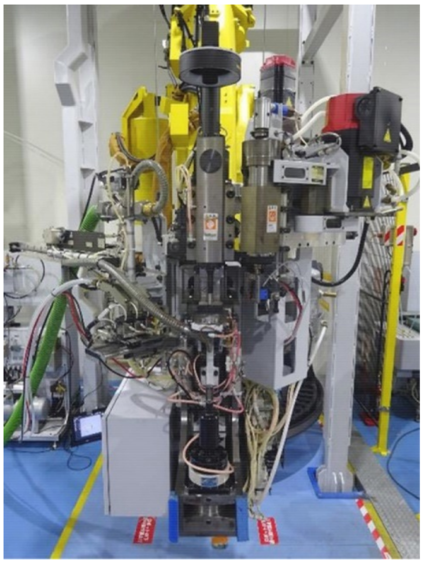

Figure 7 Newly developed end effector

2.4 Clip KIT feeder

This equipment also requires a device for automatically identifying and feeding clips because it is necessary to identify and pick up as many as 3 000 clips of 950 types.

For that purpose, we have developed the KIT feeder shown in **Figure 8**. The feeder is equipped with an 11-stage stocker like those found in an automated warehouse and automatically feeds clips to the position where the robot grips it. The KIT box is used with a KIT plate dedicated to each stringer in which clips are stored as shown in **Figure 9**. By using replaceable KIT plates, quantity management has been minimized and the occupied area can be reduced. The worker places the parts in the KIT plate where the part number is written. The KIT plate is provided with a groove to prevent misalignment during transportation. The feeder has a clip identification function. The part number of a clip stored in the KIT is read and collated by image processing. The collation result is displayed on the PC at hand of the operator. Processing of incorrect clips is automatically skipped, which makes it possible to eliminate assembly mistakes.

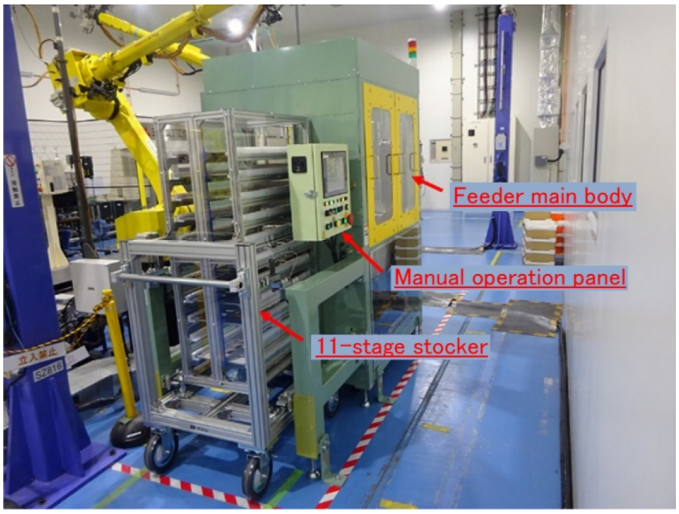

Figure 8 Clip KIT feeder

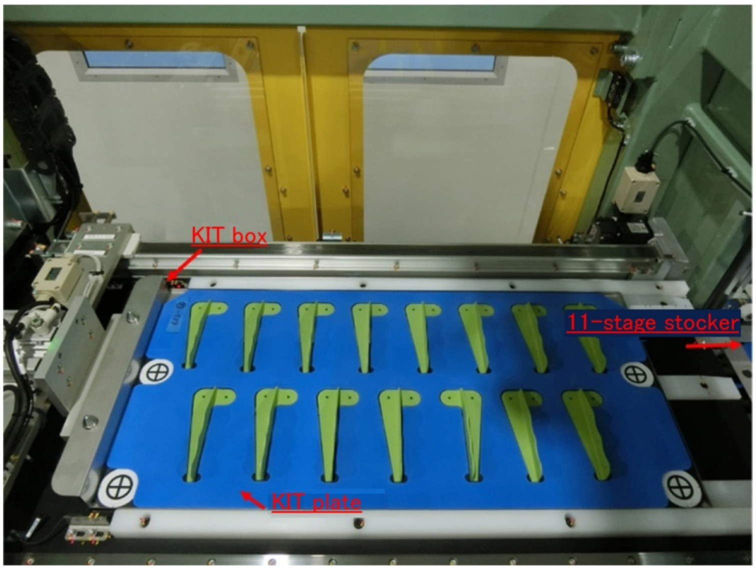

Figure 9 Clip KIT box

3. New technologies applied to robotized assembly equipment

3.1 Elimination of jigs utilizing the freedom of robots

The conventional assembly method requires many changes of the positioning locator jigs and tools on a standard large stationary jig and tool in order to position and process a stringer and clips, so it takes much longer to changeover jigs and tools compared with the processing time. This equipment consists of robots that are set on common spatial coordinates, allowing stringers of all shapes to be gripped and processed due to the 6-axis degrees of freedom that the robots have. As a result, jigs and tools can be completely eliminated.

In addition, the robots that grip a stringer have a system for teaching a program created off-line while executing automatic correction with laser trackers, which makes it possible to reduce the enormous amount of teaching time that is required in introducing robot equipment.

3.2 Establishment of high-precision positioning and reduction of cycle time

A total of three robots—two stringer positioning robots and one clip positioning robot—are corrected by three laser trackers to successfully meet strict assembly accuracy requirements. For the position correction of each of these robots, it is not enough to measure only one point in space and it is necessary to correct the inclination of the joint surface between the parts. For that purpose, it is necessary to measure any three points of the clip gripping area with a laser tracker to grasp the inclination of the part, but the tracker measurement of the three points is an obstacle to shortening the cycle time. Therefore, this equipment uses Leica T-MAC to acquire 6 degrees of freedom of roll, pitch and yaw in addition to coordinates X, Y and Z in one measurement, in order to achieve both high-precision positioning and shorten the cycle time.

3.3 Development of off-line program system

The program used in the robot equipment requires teaching of the operation route using the actual machine, which takes an enormous amount of time. Therefore, we have developed a new off-line program system that enables program creation and operation simulation in advance. This system uses Dassault Systèmes' DELMIA ROBOTICS to create robot movements. Normally, to create a robot program, it is necessary to manually input and output a large amount of data such as the gripping position and operation order of the robot, which takes time. However, this system together with the development of a program creation support tool that has a function to automatically acquire the coordinate data of the robot gripping position and output it to an Excel file enables shortening of the program creation time.

4. Future prospects

Since June 2019, we have applied the robotized assembly equipment to the assembly of singly-curved surface stringers and clips and as of August 2021, 90% of the stringer processing has been incorporated into this equipment. By utilizing laser tracker measurement, the equipment has achieved an assembly accuracy three times greater than that of the conventional method. The equipment has also realized unmanned operation, enabling a 50% reduction in labor. In the future, we will promote the application of the robotized assembly equipment to multiply-curved surface stringers (**Figure 10**) where the effects of twisting and bending of the stringer are more pronounced.

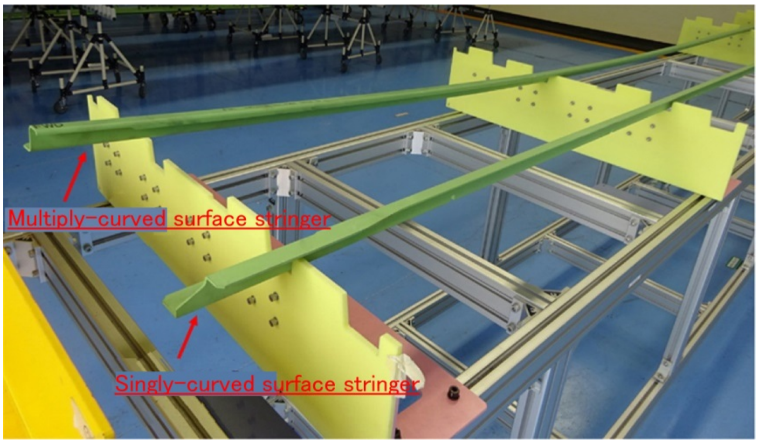

Figure 10 Singly-curved surface stringer and multiply-curved surface stringer