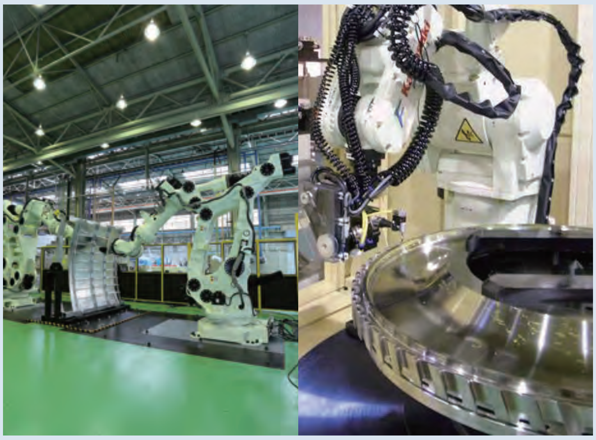
Development of New Joining and Finishing Technologies for Aircraft Fuselages and Engines Using Robots



More jetliners are expected to be manufactured in the future in line with an increase in the demand of plane passengers.

Automation using robots is garnering attention in the field of aircraft manufacturing since it is required to further reduce production costs and accelerate the production rate while satisfying stringent quality requirements. In this context, we are developing robots, systems and production processes suitable for automation and are moving ahead to apply them to actual parts of aircraft fuselages and engines.

Introduction

Over the next two decades, air traveler numbers are expected to increase by 4.6% a year on average, and it is anticipated that 33,000 new passenger jets will take to the air in the same time. On the other hand, price competition is becoming increasingly intense, and customers are demanding lower manufacturing costs.

1 Background

Recent years have seen not only the development of fuselages for the Boeing 777X and Airbus A350, but also engines for them, and even more new passenger plane models are also expected to enter development. As a partner in the joint development and joint production of aircraft fuselages and engines, it is critical for Kawasaki to focus on sophisticated quality control, cost reduction, higher production rates and weight reduction. To address to meet these requirements, we are promoting the development of both automation technology and new production technology. In particular, we are concentrating on automation by robots, which are less expensive and more flexible than dedicated equipment.

2 Policy to Apply Robots to New Joining and Finishing Technologies

(1) Fuselage Production

As for aircraft fuselages, we are considering applying the Refill FSJ (Friction Spot Joining), which was developed by our company. To date, we have evaluated prototype components and joint coupons produced by robot equipped with the standard C-type FSJ gun[1]. However, because the shapes of some components makes it difficult to use a standard FSJ gun, it became necessary to develop robot and control technologies that enable joining of components of various shapes, including large primary structures.

To solve this problem, we are developing methods and systems for joining by placing robots that independently hold FSJ guns and backing guns opposite each other, as shown in **Fig. 1**[2]. In this way, for example, it becomes possible to join parts that are mounted on the fuselage skins, such as the large components in the section we are responsible for producing for the 777X. This robot is a high-rigid robot named the MG10HL, newly developed to retard distortion caused by the reaction force at the time of joining. It has a function to correct slips caused by the pressure that is applied at the time of coordinated action and joining by two robots.

In this way, while developing robots and their control technologies for applying the Refill FSJ, we are also considering robot systems, including their layouts and how they hold joined parts.

(2) Engine Production

Aircraft engines can be classified into static components as represented by cases and stator vanes, and rotor components as represented by disks and rotor

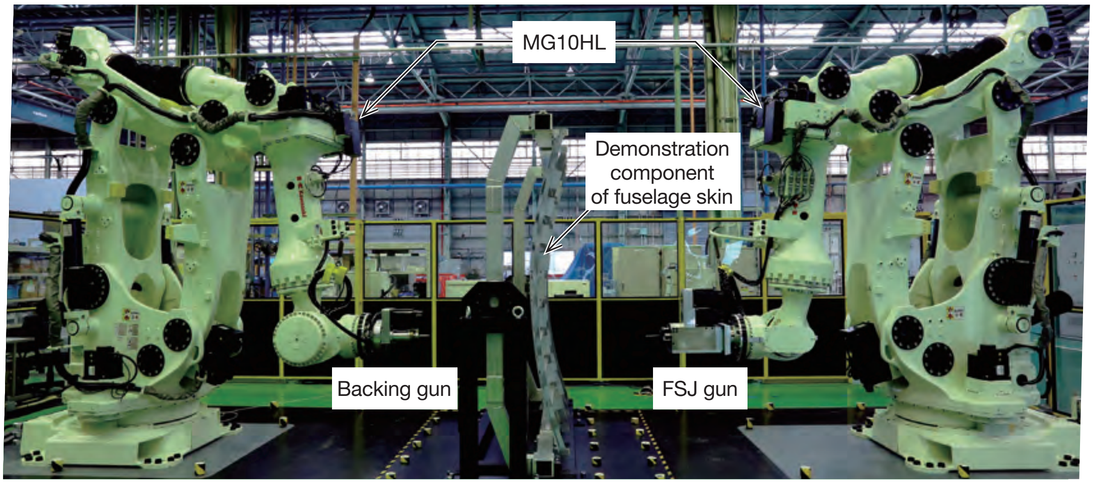


Fig. 1 Coordinated refill FSJ robot system

blades. Particularly as rotor components turn at very high speed, if they have a slight flaw or a dent, a crack can suddenly propagate from such a point, leading to the engine exploding in the worst case. As even a slight flaw could lead to a serious accident like this, stringent requirements and standards are applied also to hand finishing. To satisfy these requirements, we need advanced quality control, highly precise processing technologies and stable production quality.

To date, the edge finishing of such important rotor components has depended on the skill of experts. To realize the automation that meets customer requirements, we have independently developed technologies that make full use of robots, and have eventually become able to satisfy the requirements and standards. At present, we operate more than 20 pieces of robot finishing equipment. They are also applied not only to disk components, but also to gear parts and static components such as cases, realizing automated manufacture for multiple customers.

We have a policy to expand the scope of applying robots in the future, not only to finishing processes but also to other fields such as assembly work, parts distribution and loading/unloading of works to and from processors.

3 Considering Applications for Robots

(1) Aircraft Fuselage Production

(i) Development of Refill FSJ Process by Coordinated Robots

Figure 2 shows the Refill FSJ's joining process. Friction heat is generated by rotating the probe and shoulder

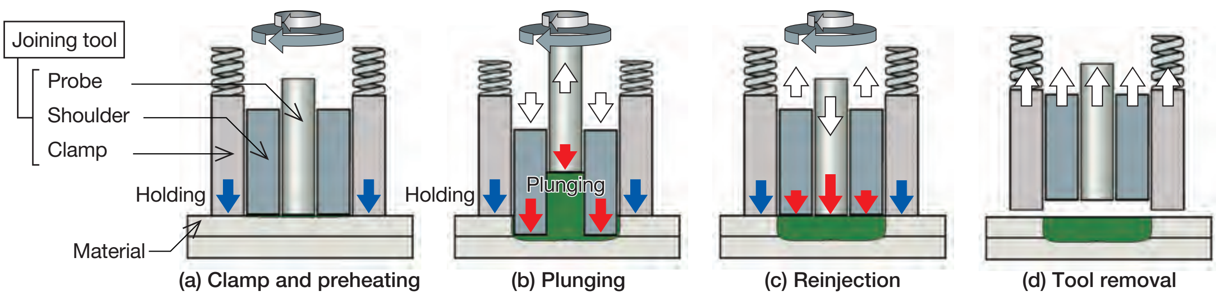


Fig. 2 Joining process of refill FSJ

together and pressing them to the material for softening, and while raising the probe and releasing the softened material, the top of the shoulder is pressed into the material. The upper and lower materials are integrated by causing plastic flow around them. Then, while pressing down the probe and backfilling the released material, the shoulder is raised.

To achieve good joining quality, we control parameters in respective processes such as probe position, tool load, rotation speed of the shoulder and probe, and plunge depth of the shoulder. To realize joining by coordinated robots, we need to synchronize the timings to start and finish respective processes and those of press-fitting and backfilling for the two robots.

(ii) Development of Joining Processes of Corrosion-Protected Materials

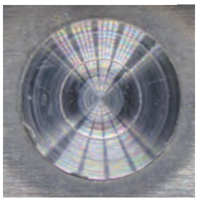
Many aircraft parts are coated with sealants to protect against corrosion at fay surface and for waterproofing. In principle, aircraft parts joined by Refill FSJ should be coated with sealant. However, if Refill FSJ is done by the joining processes described above, sealants would be caught in the joint, causing internal defects and loss of strength.

To prevent this problem, we developed a joining process for sealant-coated materials[3]. The process involves squeezing out the sealant that is coated on faying surfaces by applying pressure to the material with the joining tool before the Refill FSJ joining process begins. **Figure 3** shows a cross-section of a joint joined by this process. This is a good joint cross-section that has almost no sealant caught in the joint. The strength of the joint is significantly greater than those joints with no squeeze-out, and tests confirmed that the strength is nearly equal to that of joints not coated with sealants.

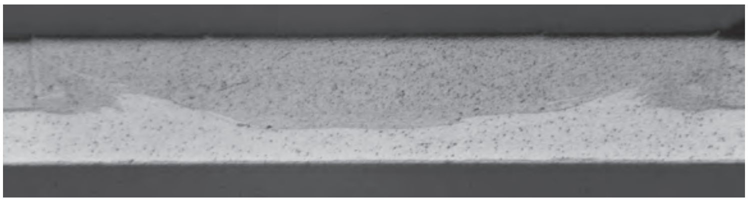
(iii) Automation of Component Layout

To automate the entire process of component production, we considered methods for having robots automatically lay out components, position them and hold them, and have prototyped systems to do so.

To avoid interference between the FSJ guns and parts, as shown in **Fig. 4**, we employ a small 10-kilogram portable robot called the RS10N is equipped with a light-weight



(a) Appearance of joint



(b) Cross-section of joint

Fig. 3 Joint appearance and cross-section in the joining process with the sealant squeeze-out

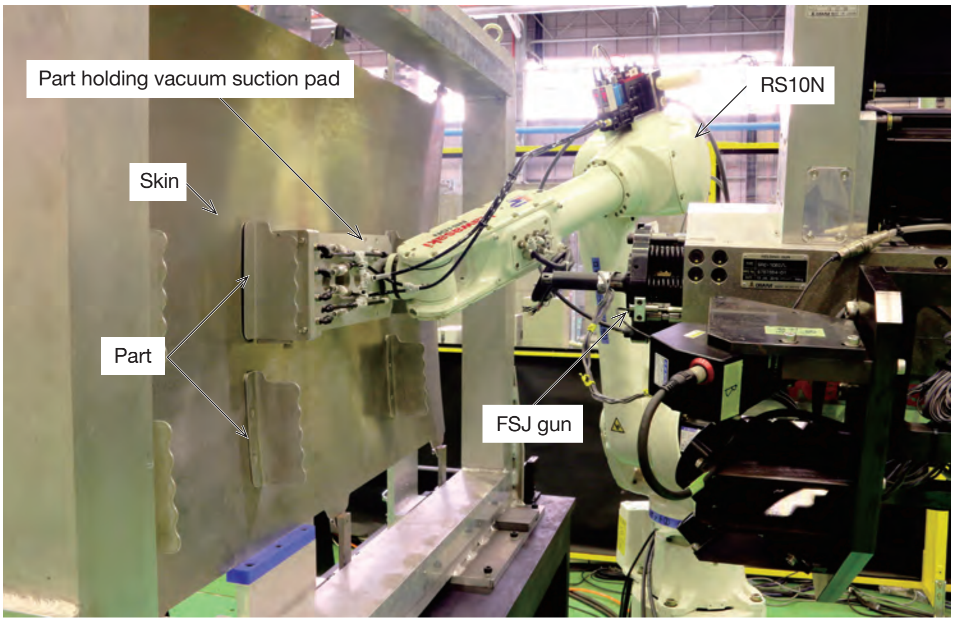


Fig. 4 Parts layout robot

vacuum handling tool to hold parts. We prototyped a system to control a total of three robots in a coordinated manner, i.e., two robots that have FSJ guns and backing guns and this part-layout robot. In doing so, we considered ensuring space to allow the FSJ guns to access joints, holding positions against reactions during joining and preventing flaws in parts. The vacuum suction made it possible to grasp parts steadily and provides clear access for FSJ guns by ensuring space around joints. Vacuum suction also made it possible to hold parts, including skins, in position and counter reactions during joining. **Figure 5** illustrates how resin blocks are laid out on contact surfaces between skins and vacuum pads to prevent flaws.

In future research, we will consider sensing and correction technologies to realize highly precise part layouts required for aircraft.

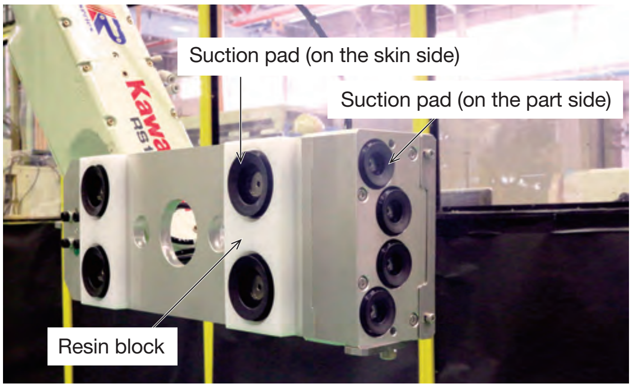


Fig. 5 End effector for holding the part

(2) Engine Production

(i) Off-line Teaching System KCONG

Usually, when motions are taught to robots on-line, robots are actually operated by people using teaching pendants. However, it is difficult to realize those motions that require precision to tenths of millimeters. To solve this problem, Kawasaki Robot has a unique off-line teaching system called KCONG (Kawasaki Common Offline NC data Generator) that makes it possible to teach complicated motions in a highly precise manner.

For example, in the case where works are machined by cutting tools mounted on robots, KCONG captures 3D models of applicable works first. Then, it creates teaching points on a personal computer as shown in **Fig. 6**, and produces machining paths for the cutting tools, making it possible to teach precise machining positions and achieve ideal motions for cutting tools.

(ii) Touch-Sensing System

With KCONG, while ideal teaching points can be found for robots, there are various problems with operating actual ones. Deviation from ideal motions is caused by absolute precision errors held by robots themselves and deflections of arms due to processing attitudes. Furthermore, works themselves do not necessarily have shapes exactly the same as those of 3D models and have individual differences within tolerances. Deviation can also result from errors that caused at the time of setting works to jigs and tools.

To compensate for the problems discussed above, we developed a touch-sensing system. This makes a three-point measurement of a part of a work in a state of being

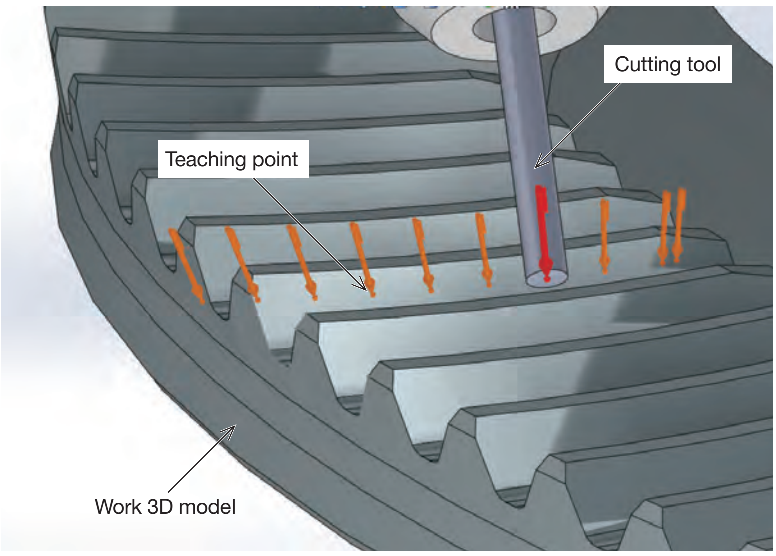


Fig. 6 Example of offline teaching with KCONG

set, derives the difference between the configured intersection point and the theoretical value, and then makes corrections.

(iii) Constant-pressure device

Even though ideal machining paths are obtained and moreover the positional deviation from the reality is corrected, uniform chamfering shapes are not necessarily obtained in all machine paths. This is because motions of robots themselves are not smooth, leaving problems in uniformity depending in some cases on the worn condition of cutting tools. In the case of processing by humans, uniformity is maintained by the skills of experts; for robots, however, other solutions are needed.

A device developed for this purpose is the constant-pressure device shown in **Fig. 7**. This device keeps the pressing force of cutting tools constant by controlling the torques of servomotors. It eliminates nonuniformity of chamfering shapes in machining paths and can achieve further quality improvements.

In realizing finishing by robots like this, it now possible to consistently achieve quality that is not inferior to experts through the development of various technologies and applying ideas to applications. As a result, we could satisfy customer requirements with regard to important rotors that require very strict quality standards. At present, robots also contribute to reducing work man-hours through application to those components that produced in volume.

In the field of aircraft engines, the application of compressors to rotor components is increasing, and robot-finishing is already applied to many types and volume-produced types of engines. Also, edge finishing of cases

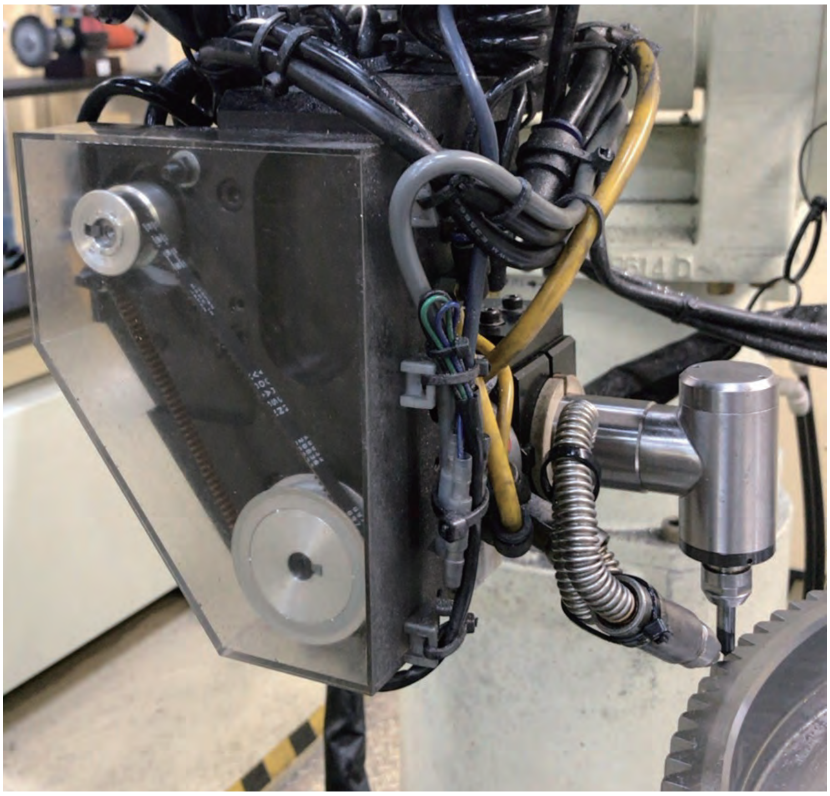


Fig. 7 Constant-pressure device with touch sensing system

that are one meter or larger in diameter and housing components can also be realized by coordinated actions of robots and rotary tables and centering-less technology. Moreover, volume-production processing is now occurring for tip finishing of high-hardness steel gear components by applying carbide cutting tools and belt sanders.

In the future, the applications will expand not only to edge-finishing processing, but also to polishing aimed at reducing surface roughness of blisk-shaped components and assembling gearboxes. The technology also holds promise for other fields such as loading/unloading of works to and from processing machines.

Conclusion

By capitalizing on our company's strengths of having in-house units to develop and produce robots to manufacture aircraft fuselages and engines, we are not only developing robots suitable for production, but are simultaneously creating production technologies with company-wide synergy by taking advantage of robot control and manufacturing technologies.

The aircraft field is an industry what will grow in the future, but competition will continue to intensify, so to expand the business we need to promote cost reductions while satisfying quality requirements. For this purpose, robot-centered automation is paramount. In this light, we will strive to reduce costs associated with quality improvement by capitalizing on the company's strengths in developing robots and systems, as well as manufacturing processes.

Reference

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2) Kitamura, Koyama, Horiuchi, Irie and Kinoshita: Ultra-Heavy Weight Transportable High-Rigid Robot "MG10HL" and Production of Aircraft Components by Using MG10HL, Kawasaki Technical Review, No. 178, pp. 14-17 (2017)
3) Patent No. 6182280, "Friction Spot Joining Tool and Friction Spot Joining Method"


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