Technology Explanation

Development of Relief Valve Automatic assembly technology

TAKIGUCHI Masaki

Abstract

Construction machinery is equipped with hydraulic cylinders, hydraulic motors, and other actuators, and these actuators are controlled with control valves (Photo 1). These control valves have built-in relief valves (RV) which restrict oil pressure and flow rate in order to protect each actuator. An RV is comprised of seal parts (O-rings and back-up (BU) rings) and metal parts, and the number of parts is large. Assembly of an RV is done by hand, and developing practical techniques for automatic assembly can reduce the burden on workers, and improve productivity and assembly quality.

This paper describes the development of automation technology for RV assembly work which has achieved improved quality and productivity.

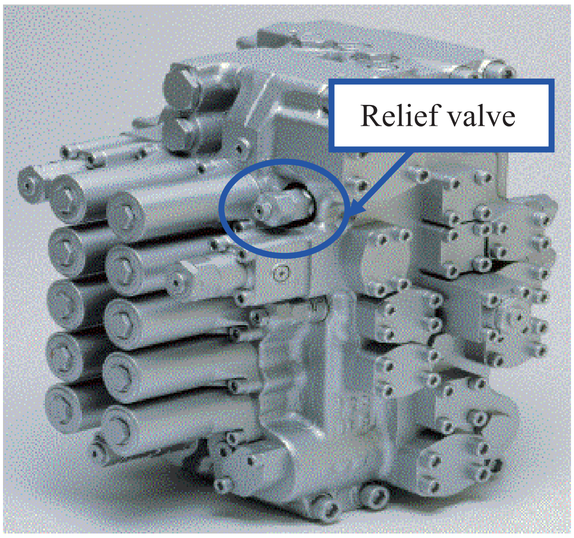

Photo 1 Appearance of control valve

1 Introduction

RVs have been assembled manually. This is because the assembling work requires human skill. For example, RVs need many parts, the parts have to be assembled with small clearance between them, and deformable seal parts need to be assembled. Since the assembled parts have a large influence on the functions of the product, the assembling work has to be carefully conducted with human senses such as visual and tactile senses.

If this work is done automatically, the burden on workers assembling parts can be reduced. However, there are many problems in automating the assembling work. For example, complex technology for assembling the above-mentioned seal parts needs to be developed and measures must be taken to prevent a decrease of the quality assurance level.

In the present work, we developed automatic assembling technology to solve these problems. Not only was the quality ensured but the productivity was also improved by manufacturing and installing mass production facilities.

2 Purpose

Development of automatic RV assembly technology and improvement of productivity by practical applications

3 Challenges

① Machine cycle time: The same as or smaller than the current level
② Productivity of output: 30% increase from the productivity of the existing production line
③ No damage to parts or assembling failure in automatic assembling

4 Requirements

To achieve the targets, we developed automatic assembling technology with the following requirements:

① The order of assembling was determined not based on the order of manual assembling but based on a viewpoint of ease of automating the assembling. The automatic assembling technology should be designed so that the assembling could proceed in this order.
② The technology to be developed should have a quality equivalent to or higher than the quality of manual assembling.
③ The assembling system has to be small enough to fit in the existing space.
④ A mechanism is necessary not to leave defective products for the downstream process.

5 Target products and target processes

Figure 1 shows the appearance of RV components. RVs consist of 20 parts, including 17 kinds of seal parts. RV assembly work consists of a parts assembling process and a parts tightening process. The parts assembling process consists of seal parts assembling and metal parts assembling processes.

The following are the features of the products and assembling process.
① The products have the same parts configuration and the same product number although they have different relief pressure and flow control value.
② Because of the single product number, a set-up change is not necessary in the assembling.
③ The production volume is large since multiple pieces are installed in a major control valve.
④ The product has many soft or compact parts such as an O ring and the assembling work needs the manual skills of workers.

Fig. 1 Appearance of RV

6 Overview of developed facilities

Figure 2 shows the appearance of our developed mass production facilities. The facilities consist of a parts table where operators feed parts to the facilities, an automatic seal-part assembling machine which assembles seal parts to metal parts, and an automatic RV assembling machine which assembles and tightens the metal parts. Each automatic machine has a four-axis joint robot suspended from the top. Therefore, the present system is an integrated system with a robot and various devices.

The major features of the facilities are shown below.
① The facilities have large doors on the front and back sides to ensure maintainability and enhance visibility
② A control panel is installed in the lower part of the facilities to effectively use and save space.
③ For improvement of the workability of logistics staff, a parts feeding area is developed on the back side of the facilities, i.e., the opposite side to the facility operators.

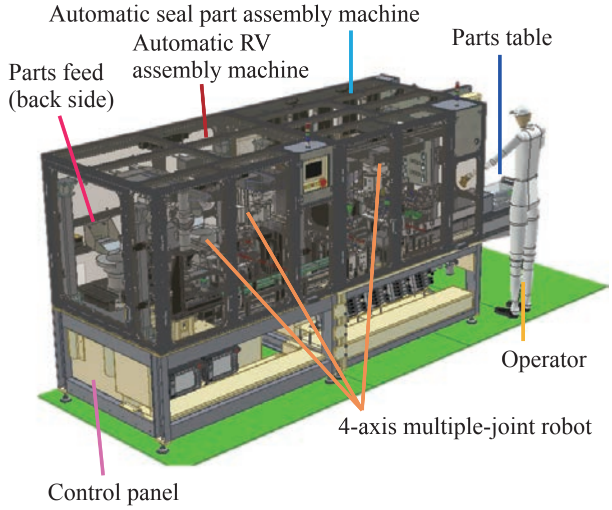

Fig. 2 Appearance of mass production facilities

7 Developed technology

7.1 Development of assembling technology

The work content of workers was analyzed before developing an automatic assembling machine. It was found as a result that they took advantage of human characteristics of smartly using both hands to repeatedly change the orientation of parts. It was easy for human work to change the orientation of parts but a dedicated mechanism and complex facilities would be necessary if a machine was used to do the same work.

However, it was also found that the seal part and the metal part can be assembled from different directions if

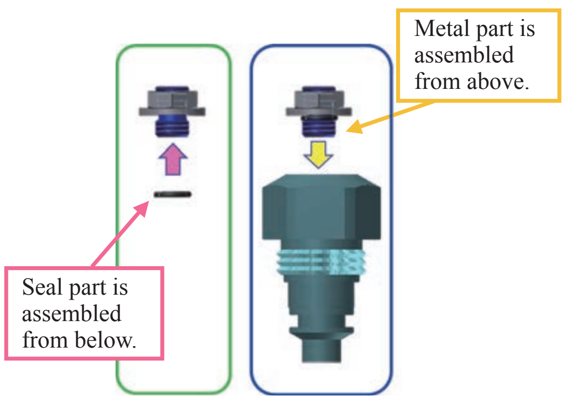

Fig. 3 Difference in assembly direction of parts

the assembling is made on different layers (Fig. 3). So we decided to use a mechanism which first assembles the seal part to the metal part and then assembles the metal part together with the seal part in order to prevent any orientation change of the parts. This realized a simple facility configuration and ensured longer machine time to be used for the assembling work.

7.2 Automatic assembling of seal parts

Here we explain the automatic assembling technology for seal parts. The following need to be taken account of to perform automatic assembling.

① The parts are flexible and hence deformable. (A BU ring has a cut face as it is bias-cut.)
② Since the attachment part has an integrated gutter shape, the seal part diameter needs to be expanded when assembled.
③ There are several points at which the O ring and BU ring are assembled and overlap with each other.

With reference to a support jig for seal parts assembling used in the existing line, we developed a guide jig taking account of the above issues (Fig. 4). The features of the jig are the following.

① The external diameter of the straight part was made larger than the internal diameter of the seal part to hold the seal part by using its strained force.
② The jig has a taper shape with its diameter expanding toward the part attachment point. The seal part expands as it moves along the taper shape.
③ The part position other than the seal-part assembled position is fitted (inserted) to the part attachment hole. So the seal part can be assembled without contacting the assembling position and damage to the parts and seal parts can be prevented.
④ The O ring and BU ring were simultaneously assembled by holding the two seal parts.

Figure 5 shows the way of assembling seal parts by using the guide jig shown in Fig. 4. The seal part put to the guide jig is moved up by the seal part push-up claw along the guide jig. The seal part is then fitted to the designated position.

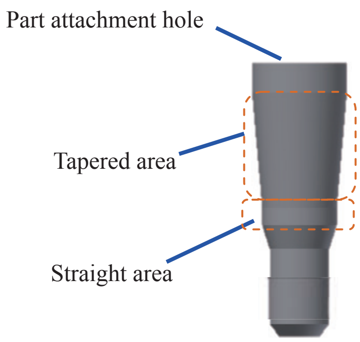

Fig. 4 Guide jig

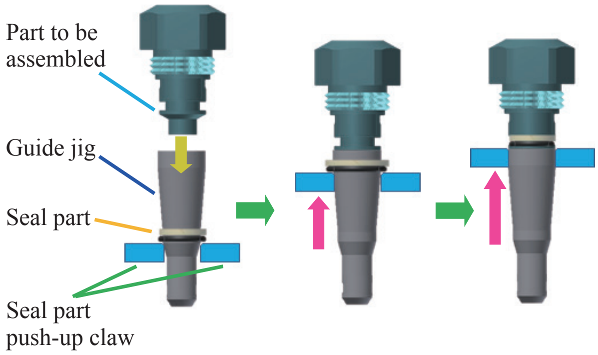

Fig. 5 Seal part assembling method

7.3 Automatic assembling of parts with small clearance

For the present automated assembling work, we introduced a robot which could repeatedly make the same motion and have high precision for the repeated positioning. However, clearance between the main poppet and the piston is smaller than the accuracy of the repeated positioning of the robot (Fig. 6). It would therefore be difficult to realize stable assembling by simple positioning control. In general, the position and force are monitored and corrected by using an image processing device and force sensor. However, additional inspection devices need to be installed for this purpose.

In the present development, we improved the robot software to make the facility configuration as simple as possible. We combined the speed optimization and compliance control [Note 1)] during the assembling process to assemble the parts with small clearance. Also, galling of the parts during assembling is detected by monitoring the electric current load rate of each robot axis to prevent shipment of defective assembly products (Fig. 7).

Note 1) Compliance control means assembly control by monitoring and regulating the electric current of each motor to realize soft motion of a target object.

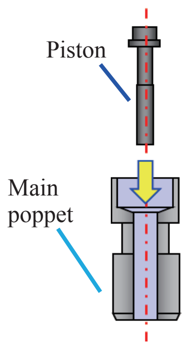

Fig. 6 Assembly with small clearance

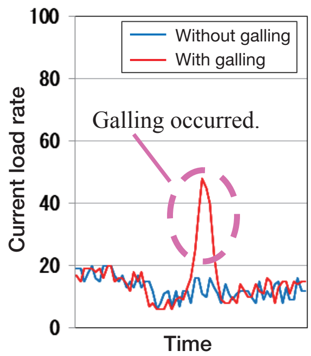

Fig. 7 Change of current load rate

7.4 Automatic tightening of adjuster

Here we explain the tentative tightening way of an adjuster to the plug. The tightening is made only tentatively because final tightening is made in the relief pressure adjustment process [Note 2)]. So the tentative tightening lasts until the O ring assembled on the adjuster comes to the plug.

Note 2) Process of setting the relief pressure of RV

The screw pitch of the adjuster is small and galling could occur when it is tightened. When an operator does this work, he/she has to adjust the pushing force and rotating force to tighten the screw. If galling occurs, he/she can feel it, loosen the screw, and tighten it again.

In the present development, we designed a mechanism of tightening the screw, using a commercial motor of moderate price to detect galling, based on the observation of the operator's work.

The selected motor was a low torque type suitable for tentative tightening. It also has a function of restricting output torque of the motor and can keep the tightening torque almost constant for all products. Also, a mechanism of detecting galling by checking abnormal torque output during tightening was introduced.

An overview of tentative tightening of the adjuster is shown in Fig. 8. The adjuster has a hexagonal hole for the tightening but the phase of the hole could randomly change. To fit in the hole whose phase is changing, a ball-type hexagonal wrench was employed in consideration of availability and ease of insertion. A floating mechanism was used to fit the tool center to the unfixed adjuster.

Then the tool can enter the hexagonal holes of the adjuster even without matching of their phases.

The above tightening system realized stable tightening quality with no failure of tentative tightening.

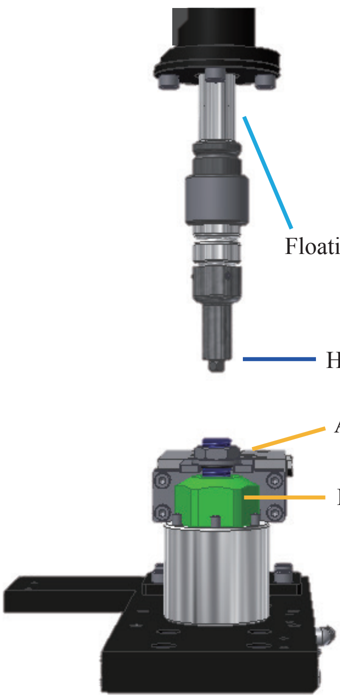

Fig. 8 Overview of tentative tightening of adjuster

7.5 Automatic assembling of small spring

Here we explain the small spring assembling technology. One of the features of the small spring is low rigidity and it being deformable due to thin wire and large ratio of L (length) to D (diameter), which could cause an unstable posture after being assembled.

When an operator assembles the spring by hand, he/she can prevent deformation or falling of the spring and visually check the posture of the spring after assembling it. To do this automatically, it is necessary to introduce a mechanism of preventing assembly abnormality (for occurrence prevention) and a mechanism of detecting the abnormality (for abnormal product shipment prevention).

In the present development, we focused on occurrence prevention and developed an assembly technology for preventing deformation and falling of the small spring. A centering shaft was introduced to the robot hand to bring the small spring, which could easily fall down when assembled, to the target position to enhance the accuracy of the assembling work (Fig. 9). In addition, a bracket is mounted on the device to prevent the small spring from falling after it is assembled and synchronized with the robot's motion of assembling the spring to stabilize the posture of the spring (Fig. 10).

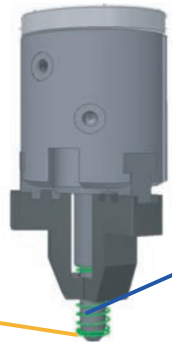

Fig. 9 Hand for small spring

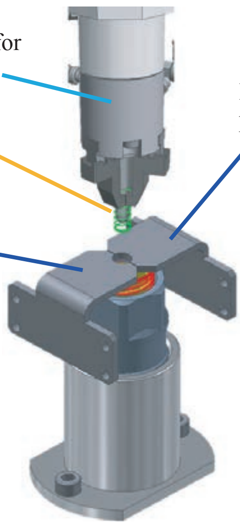

Fig. 10 How to assemble small spring

7.6 Automatic application of grease

RV components make a sliding motion when the pressure is released from the control valve. The component to which the seal part is assembled with the BU ring also slides. To prevent reduction of sliding performance, grease is applied to the seal part. Otherwise the pressure release function is influenced.

When observing the side face of the areas to which the grease was applied, one can find that the BU ring's side face is plane and the O ring's side face is curved (Fig. 11). To realize an automatic mechanism of uniform grease application, the grease application needs to be adjustable for various shapes of the surface.

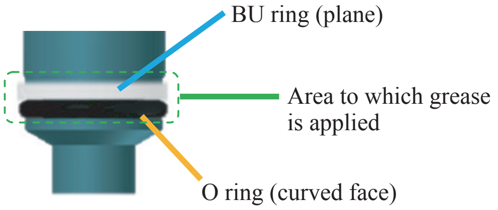

Fig. 11 Magnified view of grease application surface

A transfer-type grease application method (Fig. 12) using an extendable roller was developed. Grease fed from a grease feeder is transferred to the roller and then to the parts.

Here is how to apply grease. A roller applies grease to the exterior of the part fixed in front of the roller while moving back and forth. The roller arm has an extendable mechanism to make the roller follow the exterior surface of the part for uniform application of grease. It is difficult for workers to deliver a stable application of grease. The present method can apply a constant amount of grease, realizing stabilization of the grease application quality.

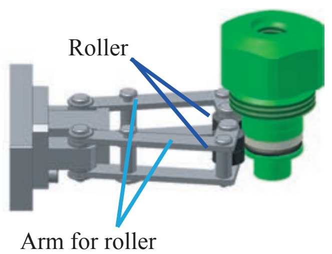

Fig. 12 Overview of grease applying device

7.7 Making facilities compact

The automatic assembling facilities explained in Sec. 7.6 and preceding sections are expected to be installed in an existing space which has been used for manual assembling work. Namely the facilities have to be made compact.

The following measures were taken to make the facilities compact.

① Use of a multi-joint robot suspended from the top allowed effective use of the space under the robot.

② The facilities were made compact by not using a general parts feeder for parts supply but developing our original picking machine.

When deciding to use the suspended robot, we were concerned about the influence of insufficient rigidity of the facility frame on the assembly performance (Mount area deviation due to robot motion: 0.3 mm or smaller as recommended by the manufacturer). So we undertook structure analysis of the frame (Fig. 13) and determined the frame size and beam structure based on the analysis result. As a result, assembling performance degradation due to insufficient rigidity after the installation of the facilities could be prevented.

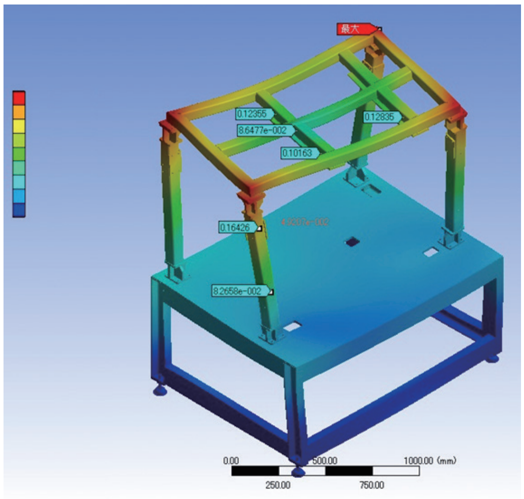

Fig. 13 Result of structure analysis of facility frame

7.8 Countermeasure against shipment of defective products

Introduction of the automatic assembling technology must not result in shipment of defective products having assembly abnormalities. The following functions were introduced to prevent such inappropriate shipment.

① Check on presence/absence of large and small assembled springs

It was difficult to detect the large and small springs assembled concentrically because both springs were made with thin wires and the spring phase randomly changed. To solve the problem, we focused on the difference in the number of turns of the springs and used a belt-shape laser sensor. The presence of each of the large and small springs was detected based on the difference of the shielding quantity (Fig. 14). The thin-wire springs can be detected as the light from the laser sensor goes straight. With the sensor array, the springs can be detected even if their phases randomly change.

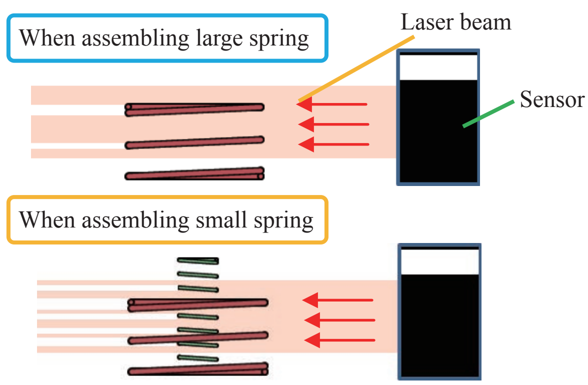

Fig. 14 Sensor to find assembled large and small springs

② Check on good/defective condition of assembled seal part and check on presence/absence of applied grease

The O ring and BU ring are assembled in a specific order. The sealing performance would decrease in case of a lack of parts or wrong order of assembling and it is necessary to check the assembling condition of the facilities. Previously, operators visually checked the assembling condition when they assembled parts. Instead, we installed an image processing device in the facilities to inspect all products for the prevention of automation-caused quality degradation.

The exterior color of the seal part is used to detect the part, and the presence and assembling condition of the seal part are judged based on the ratio of the area occupied by the designated color to the designated area (Fig. 15). Also, the presence of grease is checked based on the color of applied grease on the exterior of the part, which is done by the above-mentioned image processing device used to check the assembling condition.

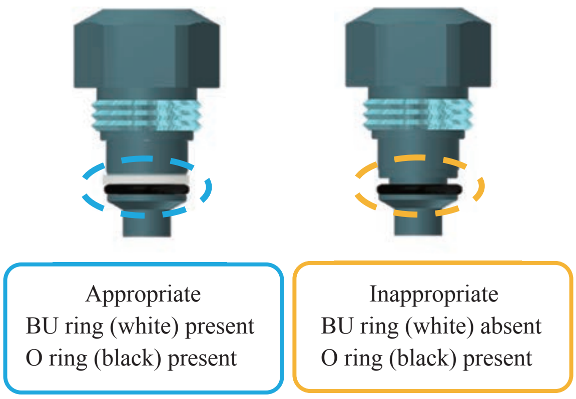

Fig. 15 Check for presence of seal part

8 Achievement of the work

① Machine cycle time: The same as or smaller than the current level
② Output productivity: 23% increase from the productivity of the existing production line
③ No damage on parts or assembling failure in automatic assembling

The target of the output productivity could not be reached. Improvement activities will continue to reach the target.

9 Concluding Remarks

New technology necessary for automating RV assembly work was developed and facilities with the new technology in place were introduced. The facilities could improve productivity.

Automatic assembly of seal parts, which had been considered difficult, was successfully developed. This technology can be used as the basis for future automated systems.

Our developed technology can be applied to work processes whose automation has not been realized because of difficulties. We would like to use the technology when a highly competitive production line is constructed.

Lastly, I would like to thank the company staff who supported me during the development and installation.

Author

TAKIGUCHI Masaki

Joined the company in 2008. R&D Sect. No.2, Production Technology R&D Center, Engineering Div. Engineering Div. Mostly engaged in the study of automation technologies.