

Low-Cost Micro-Assembly Machine

● Koichi Shimamura ● Yasunori Sasaki ● Masanao Fujii

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Recently, production demand in manufacturing industries has changed drastically from demand for high-mix, low-volume production to that for high-mix, variable-volume production. At Fujitsu, we are promoting innovative engineering through the effective use of existing equipment without the need for additional investments and by implementing the Toyota Production System. Two major themes of manufacturing in the future will be the creation of strong production systems that can adapt to market changes while holding down investment and eliminating waste and the development of equipment suitable for those changes. To assist in this area, Fujitsu now offers a low-cost, ergonomically designed micro-assembly machine that can be used in comprehensive applications ranging from small trials to mass-production. This machine has the high speed and accuracy of existing equipment and provides greater flexibility and economy during manufacturing and product changes. This paper describes this new machine.

1. Introduction

Recent years have seen a drastic change in the production demand in manufacturing industries from demand for high-mix, low-volume production to that for high-mix, variable-volume production^{1),2)} and the increasing implementation of production systems such as the Toyota Production System and the cell production system.³⁾ For example, in the electronic device field that supports the production of information transmission equipment, rapid progress can be seen in product downsizing and sophistication even while product lifecycles have become extremely short. The equipment required for the production of these ultra-small devices, from small trials through to mass-production, must be physically small while at the same time enable the use of high-precision processing and mounting technologies and flexible, precise, low-vibration handling technology. Frequent changes to the component elements and processes occur at the small trial

level, and therefore the mounting and assembly equipment must be able to handle such changes with speed and flexibility. At the mass-production level, high throughput and expandability are being demanded. Furthermore, compact, low-cost equipment is required at both the trial production and mass-production levels. At Fujitsu, we are currently developing a low-cost micro-assembly machine that enables the construction of a desktop production line.

In this paper, we describe the development of the high-precision positioning technology employed in our low-cost micro-mounting and assembly unit. We then describe the development of our parts supply technology, which is one of the most important technologies for the effective use of the unit and the production line. Finally, we describe the low-cost micro-assembly machine that was designed with these development technologies at its base.

2. Development of automated equipment for high-mix, variable-volume production

In this section, we first describe the automatic assembly machine we designed for high-mix, variable-volume production.

2.1 Issues concerning production diversity

At Fujitsu, it was general practice to use a die bonder,^{note)} which is a machine that enables high-speed, high-precision mounting and assembly of micro-devices. A die bonder is ideal for high-volume production, but is not suited to high-mix, variable-volume production such as that required at the trial production level. This is because of the machine's high initial investment cost, long period before stable operation, and large size.

Moreover, the component elements used to configure this equipment are becoming increasingly modular and downsized, and space-saving, energy-efficient desktop robots are also being offered to enable setup in a short time frame. However, in fields where the mounting and assembly of sensor devices and so forth have a direct influence on product performance, it is difficult to say that the high-speed, high-precision handling requirements are being met by this type of equipment. The following is an overview of the mounting and assembly equipment required for this type of high-mix, variable-volume production.

1) In general, trial products are manufactured several times in a company's product development department in the pre-mass-production stages. Most of the pieces of equipment used to manufacture these trial products are combinations of simple general-purpose units that are mainly manually operated, and the manufacturing conditions and other important details are

note) A machine with a surface area of approximately 1 square meter, a height of around 1.5 meters, and a weight of several 100 kgf used to mount chips cut out of wafers onto lead frames and ceramic substrates at high speed and with a high level of precision.

determined by the simplicity of the equipment used. For mass-production, the manufacturing conditions must be further adjusted to match those of high-precision manufacturing equipment, thereby requiring a considerable amount of time to establish mass-production operation. Accordingly, there is a demand for assembly equipment that can be used for both trial production and mass-production without having to change the setup in between.

2) Current demands with regard to high-mix, variable-volume production are for the ability to handle short-term, high-volume production and for equipment that can flexibly handle model changes while still maintaining high-speed production.

3) A compact, low-cost assembly machine that delivers high space productivity and can also be used for several product generations will become necessary.

2.2 Development policy and product concept

To provide solutions to the issues described above, as the central theme of our development policy, we started development of a fast, automated, and compact assembly machine that uses a base machine concept. We then developed a low-cost micro-assembly machine.

1) Compact design

Our aim was to develop an automatic assembly machine with the frame, mechanisms, and controls all contained in a single 100 mm-width × 300 mm-depth × 300 mm-height unit that weighed less than 10 kgf so it could be carried by one person. The assembly machine would enable standalone desktop operation and be linkable with other assembly machines to form an instant production line. This product concept enables a fast, flexible response to changes in the production process. Moreover, making the unit assembly machine compact and lightweight increases its rigidity, and because it is not affected by the installation conditions, it delivers high speed and

high precision.

2) Base machine concept

The assembly machine comprises a base machine consisting of the frame and a conveyance/positioning mechanism and a custom unit with hand unit and automatic alignment mechanisms that directly access the workpieces and assembly parts. The use of a base machine reduces costs and development time and enables the assembly machine to be used over several product generations. Moreover, because the custom unit is independent of the base machine, technological resources can be concentrated on the development of elemental technologies, leading to an improvement in the quality of the assembly machine.

In the following sections, we introduce the micro high-precision positioning technology and the parts supply technology that are the principal technologies of the low-cost micro-assembly machine. We then describe the low-cost micro-assembly machine itself.

3. Micro high-precision positioning technology

To combine high-precision mounting and assembly operations with high-order assembly line functions within a restricted space, we developed a conveyance/positioning mechanism with a built-in feed function, as well as a visual recognition alignment technology.

1) Conveyance/positioning mechanism technology

The positioning error of the mechanism due to the dimensional tolerances and thermal expansion/contraction of its mechanical components can be reduced by limiting the mechanism's operational range. Therefore, the high-precision parts of this mechanism use ball screws with small travel ranges and roller conveyers are only used in the conveyance mechanism. The ball screws and roller conveyers are contained in the same mechanism but are independent of each other, and the use of roller conveyers simplifies the conveyance mechanism. The repeat positioning precision is shown in **Figure 1**. This is a good example of a

high-precision ball-screw mechanism, and we can see that the precision is improved by restricting the drive area to the fixed-end side of the drive mechanism unit.

2) Image-processing alignment technology using visual recognition

Mounting and assembly requires not only a high repeat positioning precision in the handling mechanism, but also highly precise alignment of the workpiece and the part to be mounted. In particular, when parts become smaller and a datum plane cannot be established, measurement/correction of the parts' shapes and any positional or rotational shift at the parts' mounting positions is required for optimum positioning. When developing this technology, we used a workpiece recognition system combined with a parts recognition system to minimize the effects of stack measurement errors from the mechanism's components and position shifts due to temperature fluctuations. As a result, we were able to establish a stable, high-speed, and high-precision positioning technology that is not affected by the shapes of the workpiece and parts or by the condition of their surfaces. The recognition

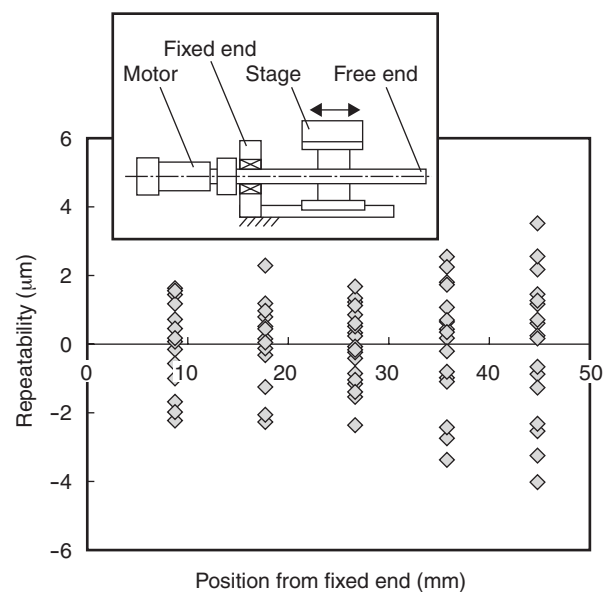


Figure 1
Relationship between distance and positioning precision.

repeatability (precision and time required when the number of edge scan lines has been selected as the parameter) for the central positions when edge measurements have been applied to the stepped section of a metal motor hub is shown in **Figure 2**.

4. Parts supply technology

To enable a certain degree of unattended operation, conventional mass-production equipment uses a system that automatically supplies parts from a large stock of parts contained inside the equipment. However, manufacturing this kind of system is a major, high-cost undertaking, and it is difficult to change it so it can handle a different product or use it for other applications. Moreover, this type of system does not meet the requirements for innovative manufacturing balanced with operational efficiency, where the stock quantity is maintained at as small a level as possible to eliminate product stagnation. On the other hand, to downsize products, parts are becoming increasingly micro-sized, making them difficult for humans to handle. Simple, automated supply units are therefore being demanded.

Against this background, we developed a low-cost micro-parts supply unit for use with the

assembly machine that we developed.

1) Parts supply technology employing a tray

The parts supply unit that we developed targets the widely-used 2-inch and 4-inch trays, because these are the most suitable trays for the parts sizes and stock quantities in general use. The parts are laid out on the tray in a matrix, and the mechanism we developed feeds the tray to suit the arrangement of the parts so they can be picked up. Because the *Y*-direction uses the *Y*-axis of the hand, this unit only has an *X*-axis, which is also the *X*-axis of the workpiece. The unit is only 100 mm × 100 mm × 8 mm, so it can easily be mounted in the assembly machine. The *X*-axis stroke is designed to be around 50 mm for the 2-inch size trays. For the 4-inch trays, the mechanism repositions the tray at the location where the full axis stroke has been reached.

2) Micro-sized parts supply technology

The conventional system generally used by a parts supply unit to retrieve micro-sized parts one by one from an aggregation of diverse parts is a vibratory bowl feeder that aligns the parts around its perimeter for retrieval. Depending on the size of the bowl feeder, a large quantity of parts can be dumped into it, and various shapes can be handled by using a sorting mechanism during the alignment process. However, because a customized bowl of a particular shape and design to suit the parts being fed is required, difficulties arise when it is necessary to handle different kinds of parts, and the costs are comparatively high.

We therefore developed a unit that can supply parts using only compressed air. As shown in **Figure 3**, compressed air is fed to the parts in the bowl, and the parts are carried along as the air flows towards the bowl's outlet (the parts supply opening). By controlling the airflow in the bowl, parts having various shapes, for example, micro-sized balls with a diameter of 0.1 to 0.2 mm, 0603 chips with a size of 0.6 × 0.3 mm, and micro screws with a size of M1.2 or smaller, can be handled. We were able to develop a low-cost supply unit capable of supplying 1000 to 3000

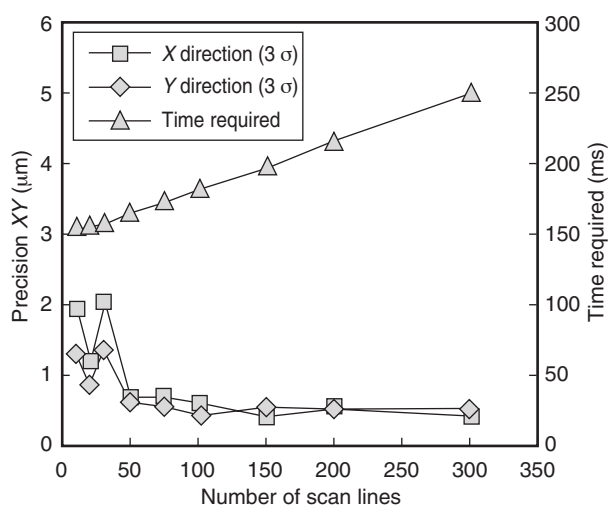


Figure 2
Recognition precision.

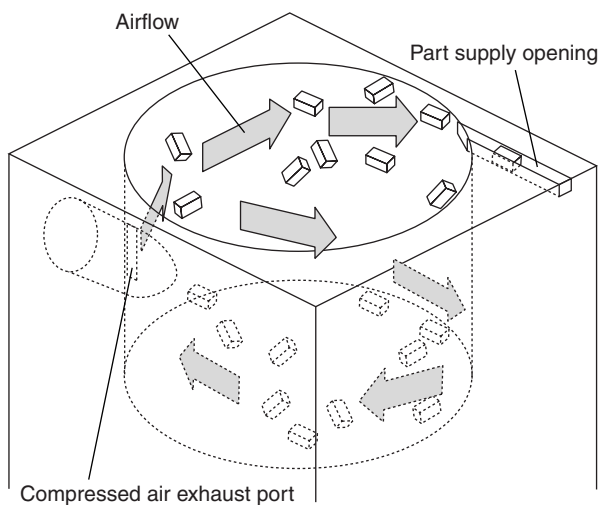


Figure 3
Principle of bulk supply.

parts at a time.

5. Low-cost micro-assembly machine

In this section we describe the low-cost micro-assembly machine that we developed using the technologies described earlier in this paper.

1) Low-cost micro-assembly machine

As shown in **Figure 4**, this assembly machine comprises the following three elements.

- A frame with a built-in unit that is used for both multiple parts mounting and assembly processes and a common base comprising the conveyance/positioning mechanism described in Section 3.
- A precision stage selection base equipped with Y-axis and alignment mechanisms for selecting the operating stroke and load-bearing capacity according to the process conditions.
- A custom aligner/Z-axis hand unit.

The basic configuration is pick-and-place.

The basic operation flow is as follows. A part that has been positioned by the aligner is held by the hand, moved to and positioned by the Z-axis and Y-axis pick-and-place operations over the workpiece mounted on the assembly pallet, and then mounted on the workpiece. After the part

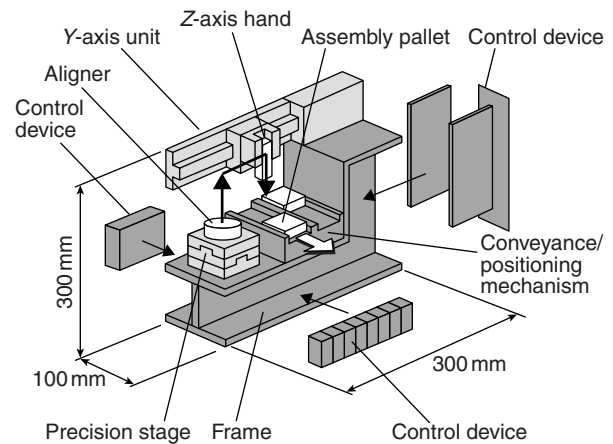


Figure 4
Configuration of low-cost micro-assembly machine.

has been mounted, the assembly pallet is fed out using the feed function of the conveyance/positioning mechanism. A positioning repeatability precision of $3\mu\text{m}$ has been realized, which makes this unit suitable for mounting sensor devices.

2) Line operation

As shown in **Figure 5**, an assembly line can be created simply by placing multiple assembly machines next to each other to form a line. That is, the linking of several of the conveyance/positioning mechanisms described earlier enables them to function as a conveyor unit, thereby creating a compact mounting and assembly line on the desktop. Moreover, the movable frame features a slide-out function to improve servicing of the machines mounted on the frame and to enable manufacturing process changes to be performed easily. When mounting chips in a package, if the assembly machines for the adhesive application process, chip mounting process, and adhesive hardening process are developed to accommodate the conditions required for each process and then linked together in a line, an automated line can be constructed that can handle production runs from the trial production level through to mass-production.

3) Assembly machine with built-in visual recognition functions

An assembly machine with built-in visual recognition functions is shown in **Figure 6**. This

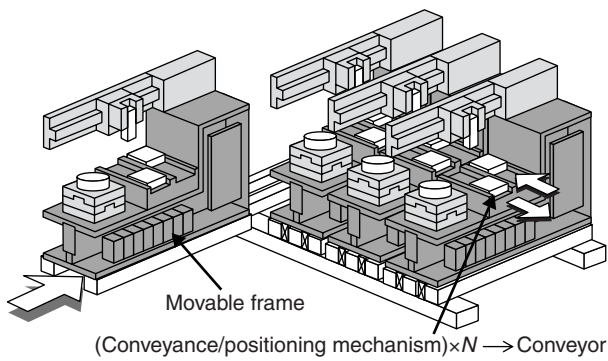


Figure 5
Assembly line.

machine consists of a conveyance/positioning mechanism, pick-and-place robot and hand, parts recognition camera, and workpiece recognition camera. The basic operation is as follows. The pick-and-place robot picks up a part and mounts it on the workpiece after any misalignment of the workpiece on the conveyance/positioning mechanism has been recognized and corrected. For a product in which a magnetic hard disk medium was mounted onto a motor hub, we achieved a visual recognition repeatability of within 1 μm .

4) Assembly machine with a parts supply unit

The precision stage and the aligner units of the assembly machine shown in Figure 4 can be replaced with different types of parts supply units. For example, as shown in **Figure 7**, the precision stage and aligner can be replaced by a parts supply unit that uses a motor to perform positioning control of the tray. Moreover, if a bulk supply unit is mounted instead of the aligner on the stage, the parts supply opening can be automatically adjusted for the type of parts being supplied.

Figure 8 shows an assembly machine for the supply and mounting of balls with a diameter of 0.1 to 0.2 mm. Apart from spherical parts, this machine can also be used to supply rectangular parallelepiped parts such as 0603 chips or screws. Moreover, because a supply unit can be constructed with a width of only 10 mm, multiple supply units can be incorporated in a single assembly unit. Accordingly, a single assembly machine can be used to mount multiple parts.

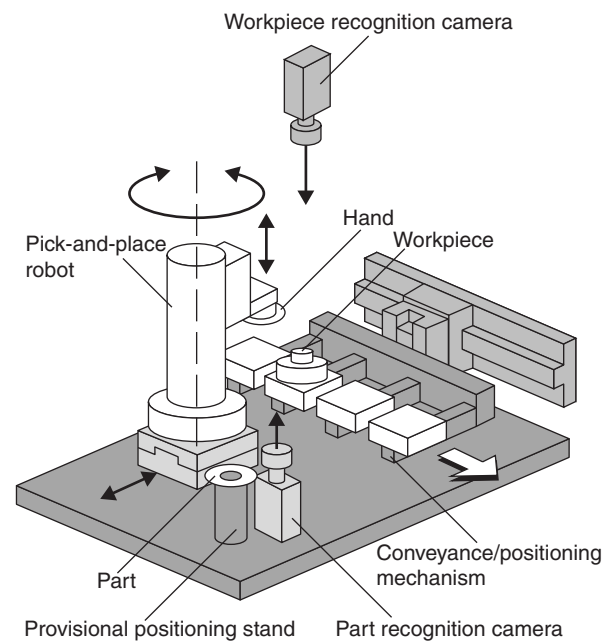


Figure 6
Image-processing assembly machine.

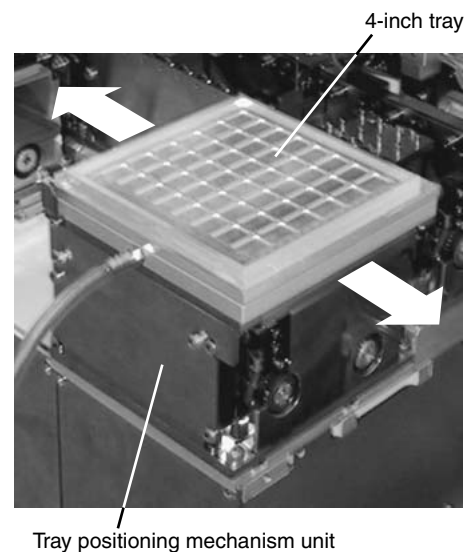


Figure 7
Part supply unit employing a tray.

5) Results

Using the conveyance/positioning mechanism technology and the visual recognition position alignment technology that we developed, we realized an easily transportable low-cost micro-assembly machine with high-speed and high-precision characteristics and a base machine structure. This machine has enabled the construc-

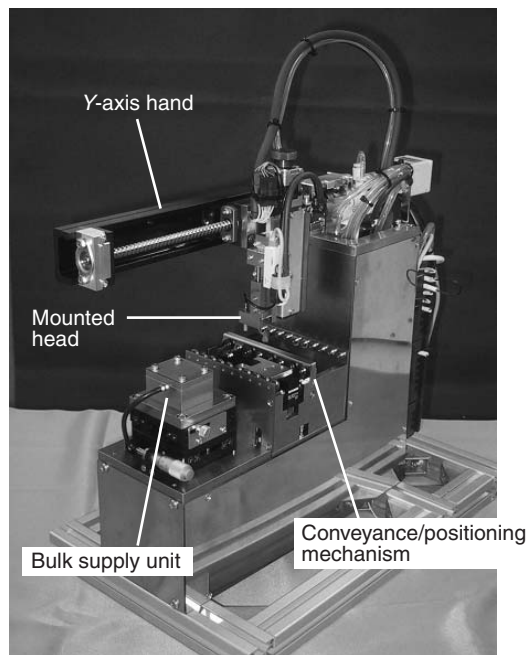


Figure 8
Bulk supply unit and assembly machine.

tion of an automated system with the flexibility to speedily adapt to the manufacturing process and product changes that will become necessary as parts become more diversified in shape and further progress is made in the development of the technology used to manufacture low-cost supply units for micro parts. The micro-assembly machine that we developed is already being used to create systems that can be used consistently from trial production through to mass-production.

6. Conclusion

As we pointed out at the start of this paper, production demand in manufacturing industries has changed drastically from demand for high-mix, low-volume production to that for high-mix, variable-volume production. At Fujitsu, two major themes of manufacturing in the future will be the creation of production systems that can adapt to market changes while holding down investment and eliminating waste and the development of equipment suitable for those

changes.

Several demands are being made of the equipment that will enable innovative manufacturing line changes: incorporation of the one-unit-flow concept, a speedy and flexible response to changes in the manufacturing process, compact size and economy, compatibility with the human-based operations performed in the cell production method, and high-speed and high-precision characteristics that are inherent in the equipment itself. Moreover, to reduce the manufacturing preparation time and strengthen innovative development to improve the design and development quality, further developments such as equipment platformization, equipment units that can be used for multiple product generations, and the concentration of development resources on leading-edge manufacturing technology will be required. The low-cost micro-assembly machine and the parts supply unit described in this paper are examples of effective measures that meet these demands. In the future, the Fujitsu Group as a whole will endeavor to play a key role in the strengthening of innovative manufacturing and development policies.

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Koichi Shimamura, Fujitsu Ltd.

Mr. Shimamura received the B.S. degree in Mechanical Engineering from Yamanashi University, Yamanashi, Japan in 1982. He joined Fujitsu Ltd., Kanagawa, Japan in 1982, where he has been engaged in research and development of automatic assembly systems. He is a member of the Japan Robot Association.



Masanao Fujii, Fujitsu Ltd.

Mr. Fujii received the B.E. and M.E. degrees in Production Mechanical Engineering from Tottori University, Tottori, Japan in 1988 and 1990, respectively. He joined Fujitsu Ltd., Kanagawa, Japan in 1990, where he has been engaged in research and development of interconnect technology for printed circuit boards. Since 1999, he has also

been engaged in research and development of assembly technology and machines for micro-devices.



Yasunori Sasaki, Fujitsu Ltd.

Mr. Sasaki received the B.S. degree in Mechanical Engineering from Shinshu University, Nagano, Japan in 1984. He joined Fujitsu Ltd., Nagano, Japan in 1984, where he was engaged in SMT and BMT manufacturing engineering. He was assigned twice to a North American manufacturing site. He is now at Fujitsu Ltd., Kanagawa, Japan, where he is engaged in development of micro

device assembly technology.