Innovative Production Processes at Azbil's Mother Factory

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The acquisition of advanced production technology for the creation of new products, the pursuit of continuous reduction in manufacturing costs, and the improvement of manufacturing quality are some of the roles of the "mother factory" that stands in the vanguard of azbil Group production. This paper describes advanced production processes utilizing sensor packaging technology acquired over many years, including the precision mounting and microassembly of parts using AI image processing technology and force-control technology. In addition, we report on our efforts to construct a globally deployable flexible manufacturing system that supports multi-product variable production and customized production in order to meet our customers' various needs, as well as our efforts to eliminate human error and to construct a new flexible production line.

1. Introduction

Azbil Corporation has integrated the production operations that were formerly distributed between its Isehara Factory (in Isehara, Kanagawa) and Fujisawa Technology Center (in Fujisawa, Kanagawa) into the Shonan Factory (in Samukawa, Kanagawa), which will serve as the azbil Group's mother factory. With a view to deploying innovative production processes, we are using the Shonan Factory as a place to verify advanced production technologies.

Currently, we are working on two types of functional enhancements in the Shonan Factory. The first of these is to improve production by acquiring production technology for the creation of new products that takes advantage of recent revolutionary technological trends. We believe that developing products with unrivaled production processes that cannot be easily imitated will lead to product specifications that only Azbil can offer, which will enable us to enhance product value as well as customer satisfaction. Secondly, we are working to promote continuous reduction in manufacturing costs and to improve manufacturing quality, and to do so on a global scale, while maintaining our system for multi-product variable production and customized production that meets the various needs of our customers, which is the strong point of the azbil Group.

To address the first enhancement goal, we are making more sophisticated production processes by adding AI image-processing technology and also force-control technology for the assembly of fine components to the sensor packaging technology that we have acquired over many years of developing products incorporating various sensors.

For the second goal, we are working to further integrate information and communication technology (ICT) into a flexible manufacturing system that supports multi-product variable production and customized production. This includes integrated production information control and automatic setting of processing conditions, as well as the development of a super-flexible production line with automated processes in order to break away from dependence on the experience and skills of individual workers and to eliminate human error.

In this paper, we describe solutions achievable through technological approaches to the above two goals and report on the attained results.

Fig. 1. The new production building at Azbil's Shonan Factory

2. Issues Surrounding Production Processes

2.1 Development of Competitive Products by Production Technology

Sensor packaging is one of the most important technologies for the development of measuring instrument products that meet the increasing need for IoT and ICT. Sensor packaging technology can be thought of as producing modules that enable the physical or electrical connection of sensors or microdevices to the electrical circuits of products. In order to reliably produce these modules, it is necessary to have accumulated the individual technologies, such as cutting or joining/bonding of brittle materials, microfabrication of metallic materials, and microassembly, as well as having the technological capability to develop machinery that implements these technologies as production processes. More advanced sensor packaging technology will enable us to make the measurement performance and quality of our products unrivaled. To own a production process based on advanced sensor packaging technology is the most important matter to be addressed by the azbil Group's mother factory, and is its main mission.

2.2 Global Deployment of Multi-Product Variable and Customized Production

Multi-product variable production and customized production to meet the various needs of customers are the strong points of the azbil Group. To support these types of production, the design of individual production processes and pieces of equipment was optimized, but an overall decrease in the efficiency of operations and use of space in our factories became more and more obvious. One solution to this problem is to expand the application of existing flexible production lines on which multiple products or models are handled by the same production processes or equipment.

In recent years, multi-product variable production has been increasingly promoted as customer needs have become more diversified. In our production processes, efforts were made to improve operational efficiency in the production plan by means such as equalizing the production quantity of each model. However, in so doing we were forced to perform component changes, assembly procedure changes, and setup changes (changes of conditions/settings) due to frequent changeover of the produced models. When customization for individual customers was added to these production processes, special components, assembly methods, and equipment specifications were added and flexible production lines became more complex, which increased the burden on the production site.

In addition, in domestic production using a flexible manufacturing system, the flexibility required for complex production processes was made possible by the high proficiency and cross-training of workers and the skills of site managers. Thus, the production system was supported by the high skill level of the workers. Expanding the application of flexible production lines requires the following: (1) establishing a process management system, including a database of digitized production information in a state that can be utilized by the production site, (2) introducing a system that eliminates human error by providing workers with accurate work instructions in a timely manner using the information in the process management system database to stabilize production quality, and (3) establishing a new flexible production line where people, machines, and systems work together.[(1)] Therefore, the second mission for the azbil Group's mother factory, in order to globally deploy flexible production, is to develop standardized production equipment, a standard process management system, and a stress-free super-flexible production line where the burden on workers and dependence on workers is reduced.[(2)]

3. Approach to Production Process Innovation

3.1 Production by Advanced Sensor Packaging Technology

3.1.1 Precision Mounting of Components

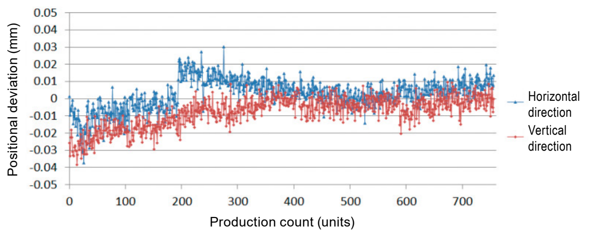
In sensor packaging, where miniaturization and high precision are required, technology for the precision positioning and assembly of minute components is essential. For example, for the model HP7 series of general-purpose self-contained photoelectric sensors, optical performance is determined by the accuracy with which the LED is positioned in relation to the lens. It is necessary to solder the LED to the PCB to within a few dozen micrometers. Previously, a camera was used to magnify the LED on a monitor, and a skilled worker manually positioned and soldered the LED while it was held in a jig. In recent years, in an attempt to automate the process, we introduced automatic soldering equipment and precision positioning by image processing. However, controlling the flow of solder proved to be difficult because of oxidation of the soldering iron and wear of the plating on its tip, which resulted in inconsistent soldering performance. In addition, with a soldering iron, a large amount of solder is supplied and flux contained in the solder is scattered all around. This scattered flux adheres to the automatic soldering equipment tool holding the LED, which hinders accurate positioning. For this reason, reliable production could not be achieved.

In order to solve these problems of soldering with a soldering iron, we switched to noncontact laser soldering.

This enabled us to introduce reliable soldering equipment which is not easily affected by changes over time like oxidation or wear. With noncontact laser soldering, since there is no longer a problem of solder remaining on the soldering iron, less solder is supplied, namely the amount melted in a single cycle only. With this method, therefore, we were able to reduce tool contamination by scattered flux. However, we could not completely prevent a phenomenon in which an LED sticks to the tool due to the viscosity of flux on the tool surface, causing a sudden deviation in the position of the LED when it was released after positioning. Also, increased temperature of the tip of the tool due to continuous mounting in short cycles caused expansion of the tool, resulting in continuously varying positional deviations. For these reasons, we were unable to achieve long-term stability. Therefore, we introduced a control method in which the mounting position is corrected by measuring the positional deviation of the previously mounted LED and sending the measurement as feedback for positioning.

A comparison of the amount of deviation in the LED's position without corrective control and with it is shown in figure 2. From the figure it is clear that without corrective control there were both horizontal and vertical deviations in the position of the LED which increased with the production volume. On the other hand, it can be observed that with corrective control, the amount of positional deviation from the target value was stable, maintaining a constant value.

A feature of the newly introduced method of control is that the amount of positional deviation of the LED is statistically processed to separate positional deviation occurring over time, on the one hand, from sudden positional deviation, such as occurs due to adhesion of the LED to the tool. Correction is applied only to the changes over time. Additionally, the timing of tool cleaning is determined automatically based on the frequency of sudden positional deviations, and an alert is sent to the responsible worker. This arrangement has enabled us to mount LEDs with high positioning accuracy.



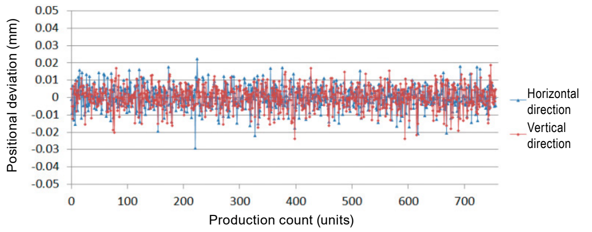


Fig. 2. Comparison of LED positional deviation without and with corrective control
(Top: without corrective control. Bottom: with corrective control.)

3.1.2 Automation of Soldering Inspection

Next, we wish to describe the inspection process for soldering. Conventionally, inspections were performed visually by skilled workers, but in the interests of production innovation we are moving to automatic inspections, which can be scaled up globally, by adopting AI-based image inspection.

In general AI learning, the system trains on images of both defective and normal products. However, at a production site, it is difficult to obtain many images of defective products. Also, if an unknown defect occurs and the system must judge whether the product is closer to a defective or to a normal product, there is a possibility that an unacceptable defective product would be judged to be not defective.[3] In order to prevent this, we trained the system only on images of normal products and created an inspection program whose algorithm prevents defective products from being passed on to the following process.

However, the biggest weakness of this method of detecting defects was overdetection caused by excessively strict judgment. With the previous automatic soldering system using a soldering iron, the quality and shape of the solder varied widely depending on factors such as the surface condition of the soldering iron and temperature changes, which made the defective/normal judgment itself difficult. Overdetection in the amount of a few times to a few dozen times the actual defect rate occurred, necessitating time-wasting visual reinspection. Now, with the newly introduced laser soldering method, we believe that inspection can be automated, since the factors causing changes and the variations in solder workmanship fall within a range that can be easily handled by the AI image-inspection technology.

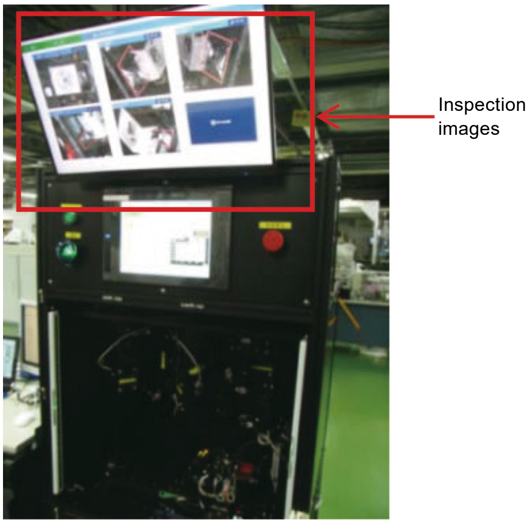


Fig. 3. Image inspection system

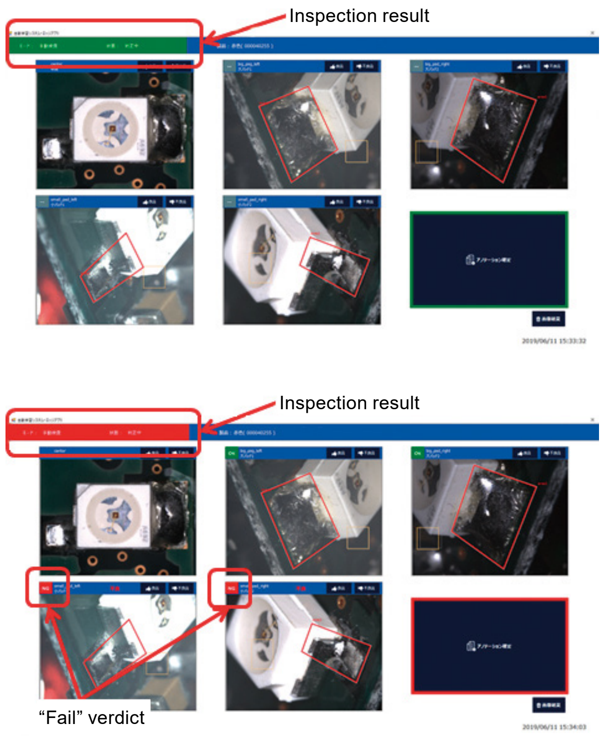


Fig. 4. Image inspection results
(top: a "Pass" verdict, bottom: a "Fail" verdict)

3.1.3 Microassembly

Sensor packaging involves the assembly (joining, bonding, etc.) of sensor chips made of brittle materials, so transport technology equipped with force control is also an important individual technology. The sensor package for the magnetoresistive sensor incorporated into the 200 series, 300 series, and 700 series smart valve positioners uses a die-bonded structure in which the sensor chip is bonded to a plastic holder. In this sensor, measurement performance is determined by the accuracy of the sensor chip's position relative to the position of the magnets that create the magnetic field. Therefore, highly accurate positioning of the sensor chip, including its height and rotation, is required. In addition, in order to prevent damage to the sensor chip while it is moved, force control is necessary when picking it up or mounting it on the sensor holder, since it is made of a brittle material. We achieve the microassembly of sensors using Azbil's active compliance technology, which simultaneously controls position and force.[4]

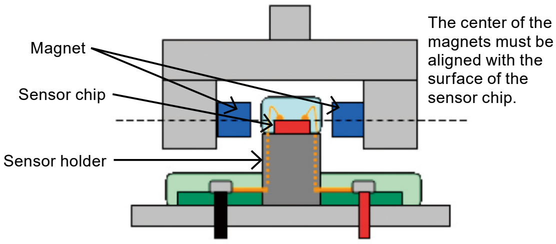


Fig. 5. Conceptual drawing of a magnetoresistive sensor

We turn now to the specific production processes for the sensor package. The sensor chip is supplied to the die bonding device on a chip tray, where image-processing equipment measures its positional coordinates and angle of rotation. The sensor chip is then picked up by a suction nozzle and its position is corrected. Next, the sensor chip is attached to the sensor holder to which a die bonding agent has been applied in advance by a precision dispenser. When picking up the sensor chip, the nozzle approaches gently so as not to damage the chip. Contact of the sensor chip by the nozzle is confirmed based on the amount of travel of the nozzle, and then the sensor chip is held.

Meanwhile, the process of bonding the sensor chip to the sensor holder with reliable positioning accuracy is being realized by pushing the sensor chip to the specified height with a force that does not damage it and that varies depending on the viscosity of the adhesive agent. Use of active compliance force control makes it possible to bond the sensor chip with reliable control of its height and rotation, which allowed us to eliminate a later mounting inspection.

Fig. 6. Magnetoresistive sensor die bonder

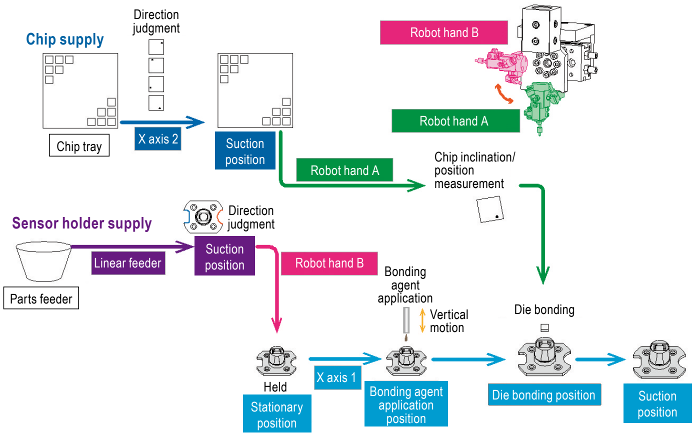


Fig. 7. Magnetoresistive sensor die bonding process

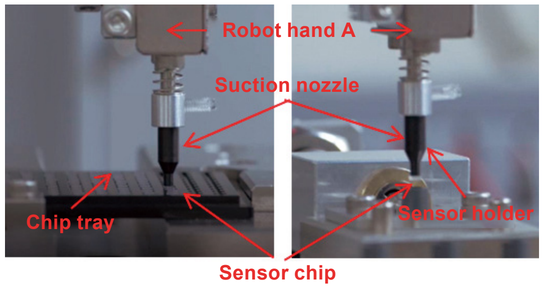


Fig. 8. Sensor chip pickup (left) and die bonding (right)

3.2 Specific Steps Toward the Super-Flexible Production Line

3.2.1 Development of the Process Management System

In order to digitize, manage, and utilize information that is input into and output from production sites, a manufacturing execution system (MES) that connects the core corporate system to the production sites is necessary. Although there are various commercial software packages, it was difficult to find one with suitable cost-effectiveness and affinity with the Azbil production system. In addition, when we first began looking into it, it was difficult to define the system requirements for the super-flexible production line. Therefore, we started by developing a process management system that performs part of the MES functions suitable for the azbil Group's production characteristics.

In the process management system we developed, the corporate core system, Microsoft® SQL Server, and the production facilities are connected via a network. The system stores various kinds of information utilized by the production site, including manufacturing instruction information (serial numbers, model identification information), production progress/history data, manufacturing bill of materials (M-BOM), and settings information for each model in the database. It can identify the production equipment to be used from within the system by recognizing individual products to be produced and automatically retrieving the necessary information, such as the processing conditions of the production equipment. In addition, it stores the output information as history data, including data on inspections during the production process and information on components, in the process management system database using product serial numbers as keys. For model GTX _ _ _ Advanced Transmitter differential pressure transmitters and gauge pressure transmitters, for example, which measure the flow rate, pressure, or liquid level of gases, liquids, or steam in plants, more than 7,800 model variations are produced each year. Therefore, production trace information that guarantees that each product has been produced through appropriate processes is important. The newly introduced process management system can retrieve this kind of information in real time.

3.2.2 Elimination of Human Error in Multi-Product and Customized Production

The risk of human error increases in multi-product and customized production, since there are many areas that depend on human management skills, such as the proficiency level of workers or whether they have multiple skills. Reduction of human involvement when picking multiple components, providing work instructions, and performing frequent set-up changes can reduce the risk of human error, making it possible to maintain a high-quality, high-efficiency production line. With the newly introduced process management system, the production equipment can retrieve component selection information for each model or equipment settings information by reading the product serial number and accessing the database. With a component selection support installation, automatic setting of a marking device to print model numbers or model-specific information, etc., it is now possible to create production processes that do not depend on workers' skills, eliminating human error from the assembly processes of multi-model products like model GTX_ _ _ Advanced Transmitter differential pressure transmitters and gauge pressure transmitters.

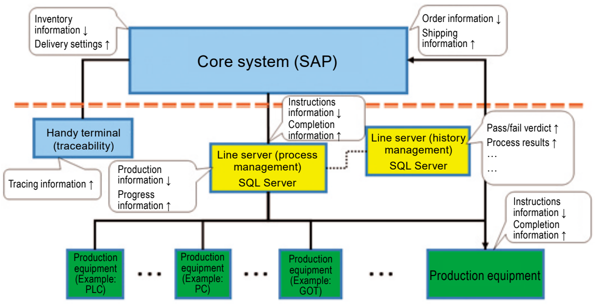


Fig. 9. Process management system overview

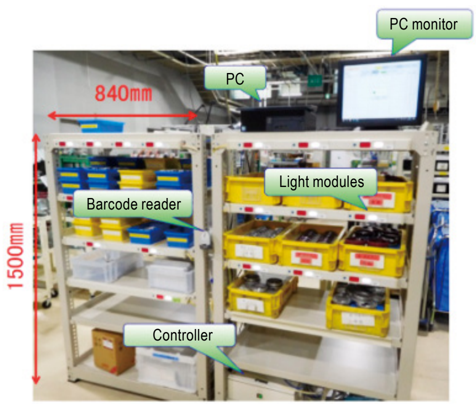


Fig. 10. Component selection support installation

Individual barcode reading for automatic equipment setup

Fig. 11. Settings for product marking

3.2.3 Creation of a New Flexible Production Line

We have rebuilt our flexible production line based on the new process management system and human error elimination mechanisms. We identified processes that could be streamlined by flexible production of product series from a production line that handles many processes for parts with common functions. Specifically, flexible production has been adopted for the following processes in a production line for gas flowmeters.

Soldering
Pressure/leakage inspection
Electrical function inspection
Flow adjustment/calibration

Even though the products belong to the same product series, there are variations in the solder pad shapes or layout for soldering on the same electric board because products were developed at different times. Therefore, in order to handle different products with the same automatic soldering device, it was also necessary to standardize the electrical board. Similarly, we standardized the parts for processes performed on the flexible production line. As a result, we were able to reduce the number of parts by 10 %.

We have demonstrated that in the production area, the flexible production line improves space efficiency and equipment operation efficiency compared to the conventional dedicated lines and equipment for each product series.

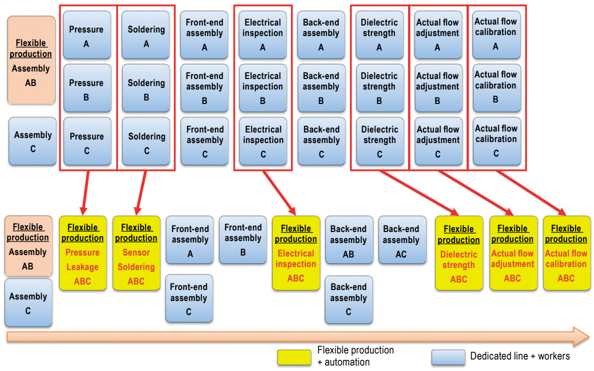


Fig. 12. Overview of flexible production

4. Results

4.1 Better Product Competitiveness Through Sensor Packaging Technology

Previously, in sensor packaging, automation was limited to the assembly process because delicate force adjustment was required for tasks such as sensor chip handling. We are now able to accelerate process automation by applying active compliance control. Production of smaller sensor packages has been enabled by combining active compliance control, noncontact laser soldering, precision positioning technology, and position control.

In addition, we have been successful in preventing downstream movement of defective products to subsequent processes by introducing AI image inspection. Its high accuracy is indicated by the fact that the rate of overdetection, which is the tradeoff when using AI image inspection, is only 1/10 that of the image inspection system that was previously used. Currently, in the area of sensory evaluation, we are working to apply AI image inspection to other processes, in addition to soldering.

4.2 Realizing the Super-Flexible Production Line

(1) Development of a process management system suitable for the production characteristics of the azbil Group
(2) Introduction of equipment to eliminate human error utilizing the process management system
(3) Development of a new flexible production line

By grappling with the above objectives, we have achieved a small-scale flexible production line with a high benefit-to-cost ratio and low dependence on workers.

In the production line we developed for gas flowmeters, flexible production has been adopted for three product series. The line occupies an area which is only approximately 50 % of the area required by dedicated lines. The operating efficiency of equipment with a long equipment takt time was improved by 17 %. We achieved an appreciable reduction in manufacturing defects by the use of automation and guidance from the process management system. Taking advantage of the opportunity presented by the development of the flexible production line, we worked with the development department to develop common product design features.

In the future, we plan to further improve productivity and quality by enhancing the real-time acquisition of information on production processes. In addition, we believe that we must reduce the time needed to design and construct production equipment through information sharing with the product design department.

5. Conclusion

Above, we describe the improvements made in production processes by using sensor packaging technology at the azbil Group's mother factory, as well as our efforts toward the creation of a super-flexible production line that can be globally deployed for multi-product variable production and customized production.

In terms of sensor packaging technology, we have actively adopted technologies such as AI-based image processing. We will continue to reinforce our production technology development in order to offer measuring instruments with unique Azbil characteristics to our customers.

To achieve a super-flexible production line, we are pursuing thorough standardization so as to carry out production of high-quality products in every factory in Japan and abroad. At the same time, we believe that we can contribute to faster development of more advanced products by using the valuable data obtained in production processes as feedback for product development.

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