

# Process monitoring for a new product management system using small production machines

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*This paper suggests a new production system with small production machines that allows low cost and high quality of the products. In the system, only the final products are inspected directly, and the quality of unfinished products are evaluated not by measuring themselves but monitoring the production process. When the production machine works normally, the product must be fine. To determine whether the machine works normally or not, we applied MT (Mahalanobis-Taguchi) system.*

*This production system needs a single molding and measurement of the production process with low noise. To meet these requirements, the authors have developed a small injection molding machine and a small press machine. Each machine has a precise force sensor in its mold for measuring the machine motion during the machining process. The small mold has a size of 80mm x 130mm x 80mm. It allows low noise measurements of the processes, and one-to-one correspondence of the product data and process data.*

*Using the small production machines, we carried out experiments to produce micro parts. The experiments showed that the new production system could determine the quality of the products from the measurement data of the machine motion. The result indicates it is possible to increase the quality of the products and to decrease the cost of the quality management.*

## 1. Introduction

Conventional industrial production system has problems concerning quality management as follows: The products are not checked by a total inspection but a spot inspection which choosing samples at random from a lot. It allows a few defective products in several tens of thousands of products. On the other hand, unfinished products such as parts and components are inspected too much. They are checked after each process. That causes a high expense for production. Functions of the products are evaluated indirectly. Originally they should be how they work. However they are evaluated by checking size, weight, appearance and so on instead their essential functions. The check itself is based on the thought of “removing defects.” When a

defect is found, the inspection items increase or the standards become strict to eliminate the defect. However There are quite many modes of defects. The method only follows the defects, and it can not eliminate unknown defects. These problems are interfering with the reduction of the defect rate and the production cost.

Conventionally, the quality control method above has been a mainstream. However, the lot management basically can not detect and eliminate all the defects. So there remain certain defects in a production lot size of ten million pieces. The rate of management cost increases in such mass production with a cheap unit price.

To overcome the problems mentioned above, the authors suggest a new production system as follows: At first, we evaluate the final products directly and totally. When the quality of final products are ensured, the intermediate inspection will be

not necessary. In that case, we only have to assure the quality of the unfinished products not by measuring themselves but by monitoring the production process. When the production machine works normally, the product must be fine. Here, the products should be selected with a point of view of 'passing the fine products.' This method can save the inspection cost without decreasing the quality of the products. To determine whether the machine works normally or not, we apply MT (Mahalanobis-Taguchi) system.

In order to know that the product is fine from the monitoring datum, the product should correspond to the process datum by one-to-one. For example, an injection molding process has to be a single molding. A process datum of a multi molding includes several data of several parts. If an defective datum is found in a multi molding process, we cannot find which one is defective. Also, two or more defective products in a lot could cancel each other. In that case, the defective products can not be detected.

Besides, for measuring the production process data with low noise, conventional production machines are too big. The big machines makes much larger value of process data with a big noise which can hide the process that we need to know. Therefore the production machines have to be as small as possible. By synthesizing small production machines with single production into an assembly line, a consecutive production line without intermediate inspection can be constructed.

In this research, in order to realize such production line, the authors develop small production machines that can monitor the process. Specifically we develop a small injection molding machine and a small press machine. Using the small production machines, we achieve one-to-one correspondence of machined products and process data. Besides, we confirm that the evaluation of products is possible by monitoring the process data.

## 2. Discrimination of the similarity by Mahalanobis-Taguchi system

In this research, we evaluate the products by monitoring the process that it was produced. When the production machine works fine, the product must be fine. In order to discriminate whether or not the production machines are working fine, at first we determine a fine state using the process data when fine products are produced. Then each time a product is produced, it is discriminated whether fine or not by comparing its production datum with that of the fine state. If they are similar, the product is regarded as fine. In case of not, the product is regarded as defective.

In other word, it is a method based on an empirical laws. The characteristics of the process data of fine products are found, and when the similar process datum is observed, the product at that time is discriminated to be a fine product. It is like a 'empirical laws.' To realize this method, a pattern recognition technology is necessary.

There are a lot of technologies of pattern recognition. and we applied MT method (Mahalanobis Taguchi method) in this research. MT method is a multivariate analysis method using Mahalanobis's space which takes dispersion and correlation of the data into consideration.

In this method, at first on a phenomenon with multi-values, a space which called 'reference space' is created from a data group of fine state. Next, on an arbitrary sample, a Mahalanobis's distance which is the distance from the center of the reference space is calculated. It describes the degree of being out of a center in a multi-dimensional space with one value. Here, the Mahalanobis's distance means the degree of difference of the patterns. The product is discriminated to be fine when the Mahalanobis's distance is small, and to be defective when large.

In this research the authors used an MT system software (KT software & consulting).

## 3. Development of small production machines

In this research, the authors developed small production machines which allows one-to-one correspondence of machined products and process data, and process monitoring with a high S/N ratio.

### 3.1 Small injection molding machine

The authors developed a small injection molding machine shown in Fig. 1.

To inject plastic material, an ultra compact pump which has a swirl shape groove is used. When it rotates, the pellets of the material are fed to the center of the swirl, and the material melted by the friction heat was injected with a pressure of up to 220MPa.

To clamp a mold, an ultra compact reduction gear is used. It has a unique planetary gear mechanism, and realizes a high efficiency, a high torque, nevertheless it is very compact. These

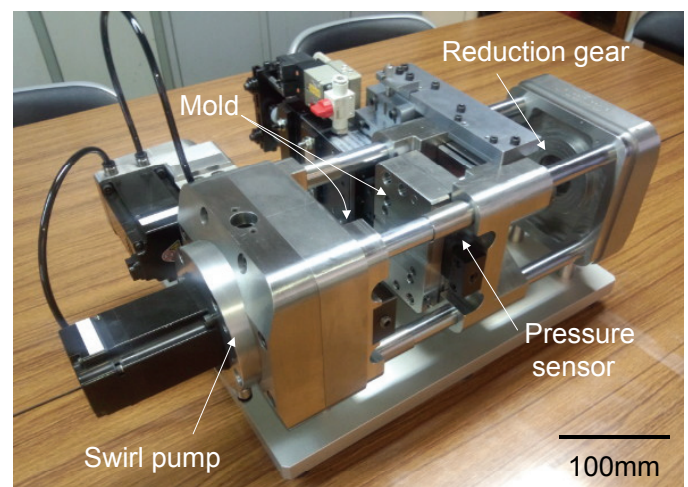


Fig. 1 Small injection molding machine.

unique mechanisms allowed the miniaturization of the injection molding machine.

In this research, an internal pressure of the mold was measured to monitor the production process. The pressure is measured by a force sensor installed at the bottom of an ejector pin (SSEBQ-01.0×100 φ1.0, Futaba Corporation). The other detail specifications is shown in Table 1.

Table 1 Specifications of the small injection molding machine.

Maximum clamping force	30 kN
Injection volume	3 mL
Maximum injection pressure	220 MPa
Mold size	80 mm x 130 mm x 80 mm C, UNiT0813
Power source	1φ 200V 20A
Size	W640 mm x H160 mm x D320 mm
Weight	37 kg

### 3.2 Small press machine

The authors developed a small press machine shown in Fig. 2. Its basic structure is almost the same as that of the small injection molding machine mentioned above. The ultra compact reduction gear with a motor achieves a clamping force of 30 kN.

In this research, a pressing force of the mold was measured to monitor the production process. The force is measured by an force sensor (LMR-S-20KNSA2, Kyowa Electronic Instruments Co., Ltd.) installed inside the bottom mold. The other detail specifications is shown in Table 2.

Table 2 Specifications of the small press machine.

Maximum pressing force	30 kN
Mold size	80 mm x 130 mm x 60 mm
Mold stroke	30mm
Maximum mold speed	50 mm/sec
Maximum cycle	80 rpm
Size	W160mm x H370mm x D160mm
Weight	25 kg

## 4. Experiments

### 4.1 Process monitoring of the small injection molding machine

In order to evaluate the performance, we carried out the experiments to mold a part shown in Fig. 3. It has a shape of a lever in a micro detecting switch. The material is a liquid crystal polymer (6030G Black, Ueno fine chemicals industry, Ltd.). The resin temperatures are 340 degrees celsius at the plasticization part, and 350 degrees celsius at the hot runner part. The injection speed is 60 mm/sec, and the maximum injection pressure is 100

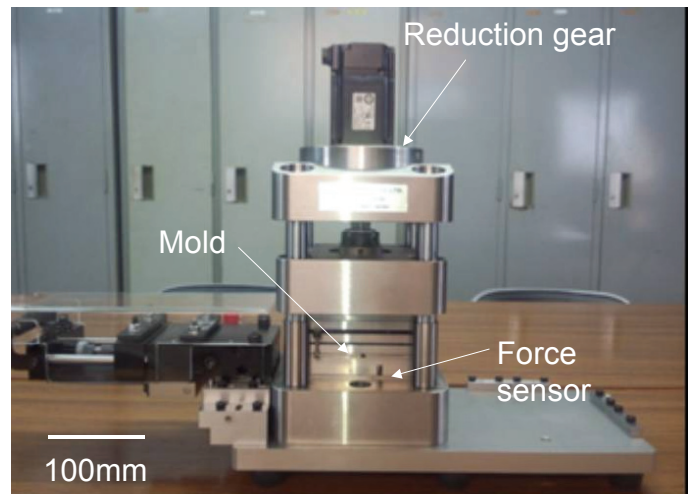


Fig. 2 Small press machine.

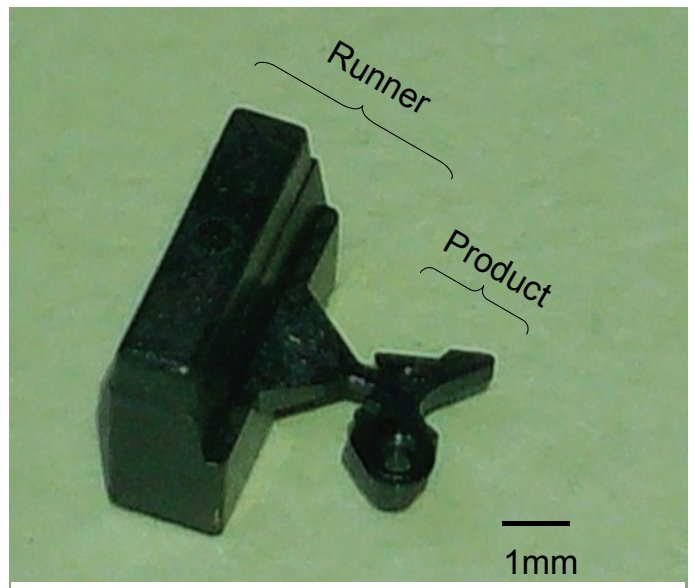


Fig. 3 Sample of a part molded in the experiments.

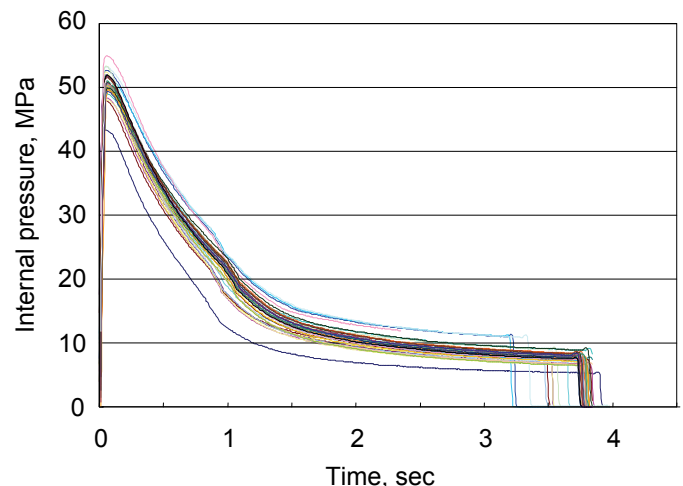


Fig. 4 Internal pressure when hundred products are molded.

MPa. The dwelling pressure is 50 MPa, and the dwelling time was 0.5 sec.

Fig. 4 shows the measured internal pressure when hundred products are molded. Each pressure curve has a slightly different shape from others. The result means the correlations of the products are reflected as such in the differences. Therefore it is confirmed that the products and the process data correspond in one-to-one because of a single molding.

Nextly, we gathered the process data when fine products were molded, and created a reference space with them. Then the MT system discriminated unknown products whether it is similar to the reference or not. Fig. 5 shows the result. The similar products are located at the left side, and the dissimilar ones are at the right side.

For a confirmation, we inspected the sizes and the weights of the products. As a result, some of the dissimilar products were out of the fine range. On the other hand, no defects are found in the similar products.

This result means that it is enough just to monitor the process for extracting fine product just monitoring a process by using the MT system for distinction. It is not necessary to inspect a product directly any more.

#### 4.2 Process monitoring of the small press machine

In the same way as the injection molding machine, we carried out the experiments to press a part shown in Fig. 6. The material is a SUS304 stainless steel plate, which has a thickness of 80  $\mu\text{m}$ . The upper mold has a weight of 2.5 kg, and it runs up and down 80 times per minutes. At that time, the force the lower mold received was measured by the force sensor settled inside the lower mold.

It has a shape of a lever in a micro detecting switch. The material is a liquid crystal polymer (6030G Black, Ueno fine chemicals industry, Ltd.). The resin temperatures are 340 degrees Celsius at the plasticization part, and 350 degrees

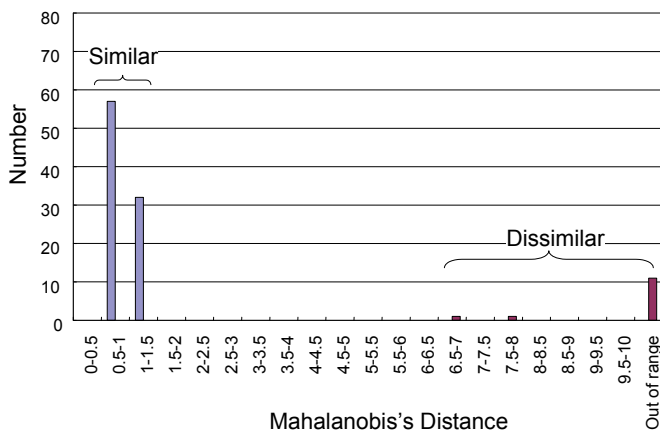


Fig. 5 Result of discrimination of the molded products by the MT system.

Celsius at the hot runner part. The injection speed is 60 mm/sec,



Fig. 6 Pressed products in the experiment using the small press machine.

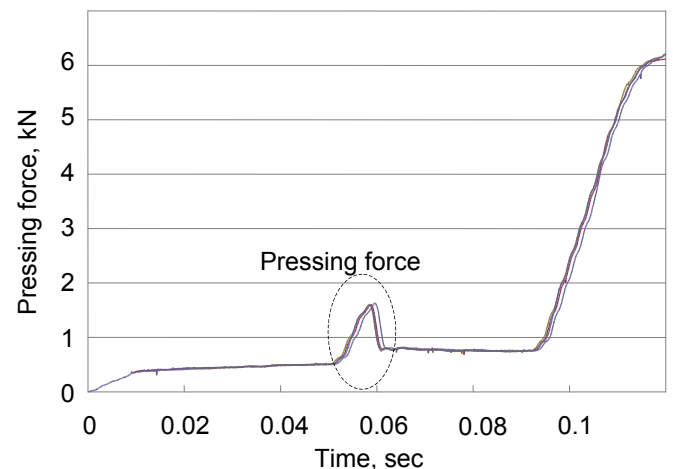


Fig. 7 Force detected by the force sensor in the lower mold during the pressing process.

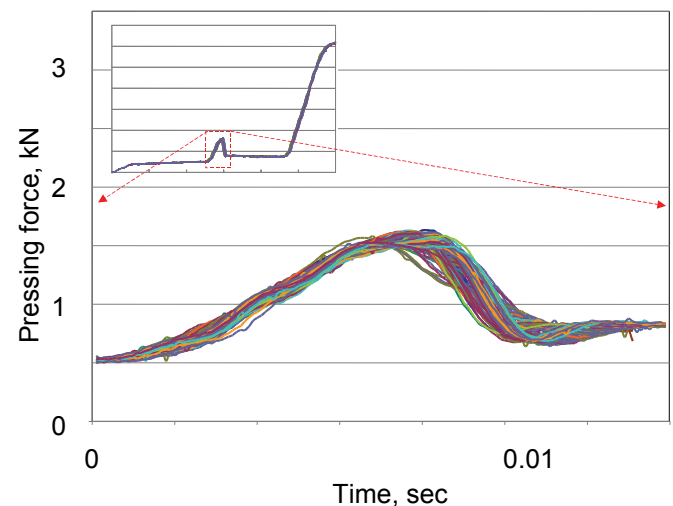


Fig. 8 Pressing force when the mold presses the work.



and the maximum injection pressure is 100 MPa. The dwelling pressure is 50 MPa, and the dwelling time was 0.5 sec.

Fig. 7 shows the result. In the graph, the force curve of the pressing a work has a small spike, which can not be observed when the machine pressed no work. Conventional press machines generally have much larger molds, which make much larger inertia forces. In those cases, the pressing forces just for pressing the materials are hidden in the inertia forces of the molds. However, the small press machine makes a small mold inertia force so that the pressing force can be detected in the total force the lower mold receives. Obviously the miniaturization of the production machine has made it possible.

Focusing on the spikes, we created a reference space with a group of fine process data shown in Fig. 8, and discriminated unknown products. The result is shown in Figure 9. The MT system clearly discriminates fine or not.

For a confirmation, we inspected all the products. The similar products contained no defective products, however the dissimilar products were all fine too, this time. This result indicates that the dissimilar products could contain some unknown defects that we have not found yet, and MT system could find them. In case that the dissimilar group has no defects, recreating another reference space including the dissimilar group will realize more accurate discrimination. As a future work, more experiments with more samples are necessary, and further analysis of relations between cause of the defects and the results of the MT system is needed.

## 5. Discussions

In the experiments in the previous chapter, on injection molding and pressing, some of the products are discriminated to be defective by the MT system, however the conventional inspections find no difference.

This result implies that unknown defects that could not be found by conventional inspections by specifications such as appearance, size, weight, and so on could be found by the MT system. Of course a conventional inspection with a more restrict standard may find them, however, it takes a higher inspection cost.

On the other hand, process monitoring using small production machines and discrimination using the MT system can decrease the inspection cost. Thus, it is expected that they achieve a production system with low cost and high quality.

## 6. Conclusions

The authors suggested a new production system which has an inspection of only final products, no inspections of intermediate products, process monitoring using small production machines and discrimination by MT method.

To realize the production system, we developed small production machines with sensors inside. They realized process

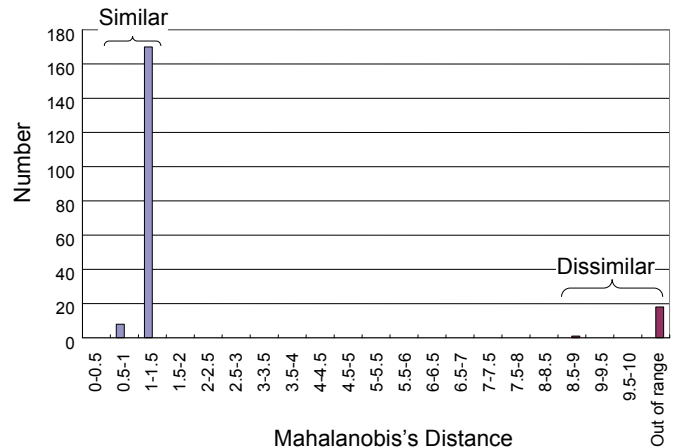


Fig. 9 Result of discrimination of the pressed products by the MT system.

monitoring with a high signal noise ratio and one-to-one correspondence between products and process data.

Using the MT system, we discriminated whether the products are similar with fine ones or not only by comparing the process monitoring data. The similar group contains no defects while the dissimilar group contains some. From this result, it is considered that a production system with low cost and high quality can be realized by the process monitoring and the MT system.

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