Elaborate Precision Machining Technologies for Creating High Added Value at Low Cost

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IT equipment consists of many precisely-machined parts, for example, semiconductor devices. Mobile phones, IT terminals, and other communication devices are becoming more compact and sophisticated as the ubiquitous computing era unfolds. These next-generation devices require miniaturized, high-precision, and high-quality mechanical components. Fujitsu is developing basic machining technologies for producing high added value at low cost. This paper outlines the following machining technologies for precision-machined parts and future devices: ultra-precise lap machining, micro-laser machining, precision injection molding, and elaborate press forming. It also gives practical examples in product manufacturing to show how Fujitsu is improving these technologies.

1. Introduction

Manufacturing is a value-added production activity, and machining technologies are the fundamental technologies of manufacturing. It is believed that Japan must develop more advanced technologies to better compete with manufacturers in China. IT terminals and other communication devices are becoming more compact and sophisticated. They require miniaturized, high-precision, and high-quality electronic and mechanical components. Fujitsu is therefore developing new machining technologies for producing these components at low cost.

This paper outlines four machining technologies for precision-machined parts: ultra-precise lap machining, micro-laser machining, precision injection molding, and elaborate press forming. It also describes how Fujitsu is improving these technologies by giving practical examples of product manufacturing.

2. Ultra-precise lap machining technology

Fujitsu is developing an ultra-precise lap machining technology for producing magnetic head sliders of small-size high-capacity hard disk drives (HDDs) for mobile devices and other consumer devices with advanced functions.[1] This section describes this technology.

The magnetoresistive layers of magnetic heads are formed on an alumina titanium carbide (Al_2O_3-TiC) substrate using thin-film technology. The thickness of these layers is made uniform to within several nm by lap machining using fine diamond abrasive grains. Fujitsu is developing a technique for managing diamond abrasive grains and lapping tools. We are also developing a mechanism that checks lapping quality in real time and a control technique that enables a high lapping precision.

2.1 Development of mechanism for multi-point lapping force control and control technique

After magnetic head elements have been fabricated on the substrate, the substrate is cut into strips called row bars, each of which contains a string of magnetic head elements. The mechanism for multi-point lapping force control enables the lapping of row bars. Resistance elements called electrical lapping guides (hereafter called ELG elements) are formed between the magnetic head elements. The lapping force at each head is individually controlled based on the resistance of its ELG element, and lapping is stopped when the resistance indicates the correct height has been reached. Then, the force is distributed within a row bar, optimizing the machining volume of each magnetic head element. A multi-point actuator has been developed to control the lapping force at each magnetic head. This actuator consists of microcylinders that control air pressure using an electropneumatic regulator and a driving force linkage; it enables machining to an accuracy of ±1 nm (**Figure 1**).

This lapping technique separately controls the multi-point actuators so each ELG element has the same resistance. However, in this technique, changes in the pressure applied by each actuator cause the applied pressures to deviate across the row bar. To cope with this problem, a multi-point control algorithm based on the least-squares method has been developed. This algorithm enables the optimum lapping force to be set at each magnetic head element based on the changes in the ELG elements. The target machining shape is a curve that is line-symmetric with the shape of the row bar estimated from the resistance of each ELG element. Based on the value obtained by subtracting the current shape from this target shape, the deviation is minimized by combining all the deformation curves. By controlling the multi-point actuators in this way, we can optimize the lapping force at each magnetic head element.

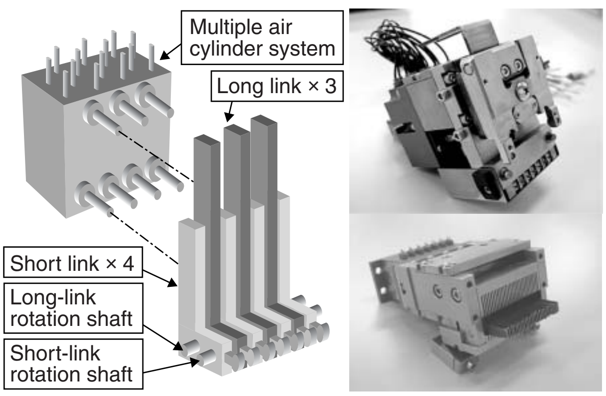
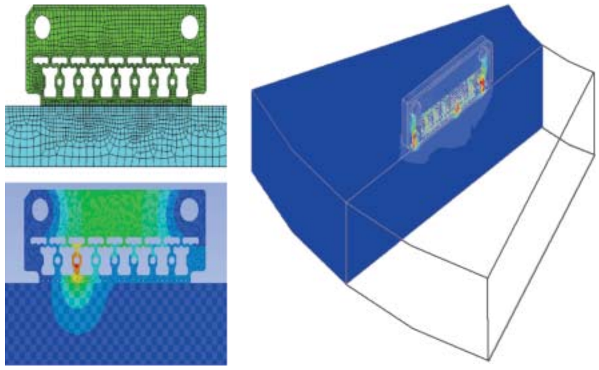


Figure 1
Structure of multi-point actuator.

2.2 Development of lap control technique using simulations

In lap machining, the rate of material removal (hereafter called the lap rate) is proportional to the product of the machining pressure and the velocity difference between the lapping tool and workpiece. This relationship is used to control lapping machines. A structure analysis tool was used to obtain the distribution of pressure between the row bar and lapping tool. The tool was also used to obtain the distribution of lap rate in the row bar based on the relative velocity between the row bar and lapping tool. Fujitsu has established a system for simulating these distributions (**Figure 2**). The obtained lap rate distribution has been incorporated into a technique for controlling machining pressure so that the mutual interference described in Section 2.1 is reduced and the machining precision is consequently increased.

This ultra-precise lap machining technology has been applied to the production of magnetic head sliders as described above. In the future, the control and simulation techniques that have been developed through production of magnetic head sliders will be further improved to produce next-generation advanced devices.



(a) 2D simulation (b) 3D simulation

Figure 2
Simulation of lap rates.

3. Micro-laser machining technology

Laser machining is performed in many production lines. This section describes laser machining technology that has been developed to produce precision-machined parts and devices and how it has been applied to product manufacturing.

3.1 Development and application of welding technique

Fujitsu started full-scale laser machining in the early 1980s with a spot welding technique that used a pulsed oscillation YAG laser to assemble print heads for wire dot matrix printers. Compared to other welding techniques, laser spot welding causes less deformation; produces stronger, higher-reliability welded assemblies; and requires no special environment or physical contact with the workpiece. Laser machining has greatly increased the degree of automation in assembly machining. This technique has been expanded to spot welding assembly of the head suspensions of HDDs and fiber-core adjustment assemblies of optical communication devices and modules. For these assemblies, the following enhancements have been made to this technique: 1) fine spotting and the use of thinner materials; 2) high-speed machining to minimize equipment investment; and 3) minimized deformation by optimizing the shapes of parts and the structure of production equipment and by minimizing the thermal stress and solidification shrinkage that occur during laser irradiation.[2)] **Figure 3** shows a laser welding machine that has a six-shaft force sensor for in-process monitoring of the magnitude and direction of deformation that occurs during butt welding. In recent years, a low-cost micro-welding technique for resin parts has been developed using high-luminance laser diodes. This technique has been used to assemble micro-camera lenses used in mobile phones. This application has established an alternative assembly method to the conventional adhesive method and achieved significant reductions in production time and equipment.

3.2 Development and application of forming and bending techniques

Next, we describe two laser micro-bending techniques we have developed.[3)] The first is used to bend the thin metal plates of the magnetic head suspensions of HDDs to correct the heads' pitch and roll angles. This is necessary because these ultra-thin components cannot be pressed and assembled with sufficient precision. This technique corrects the shape of these plates to a precision of ±0.01 degree without deteriorating the heads' vibration characteristics. The second is a ceramic bending technique for correcting the shape of the flying surface of magnetic head sliders. During the grinding and lapping of a magnetic head slider, the slider is deformed due to skew between the slider and the abrasive tool. This deformation makes it very difficult to obtain the required shape precision. The ceramic bending technique corrects this deformation to a precision of ±3 nm by irradiating the flying surface with finely-focused laser light.

3.3 Micro electro mechanical systems (MEMS)

The market for micro electro mechanical

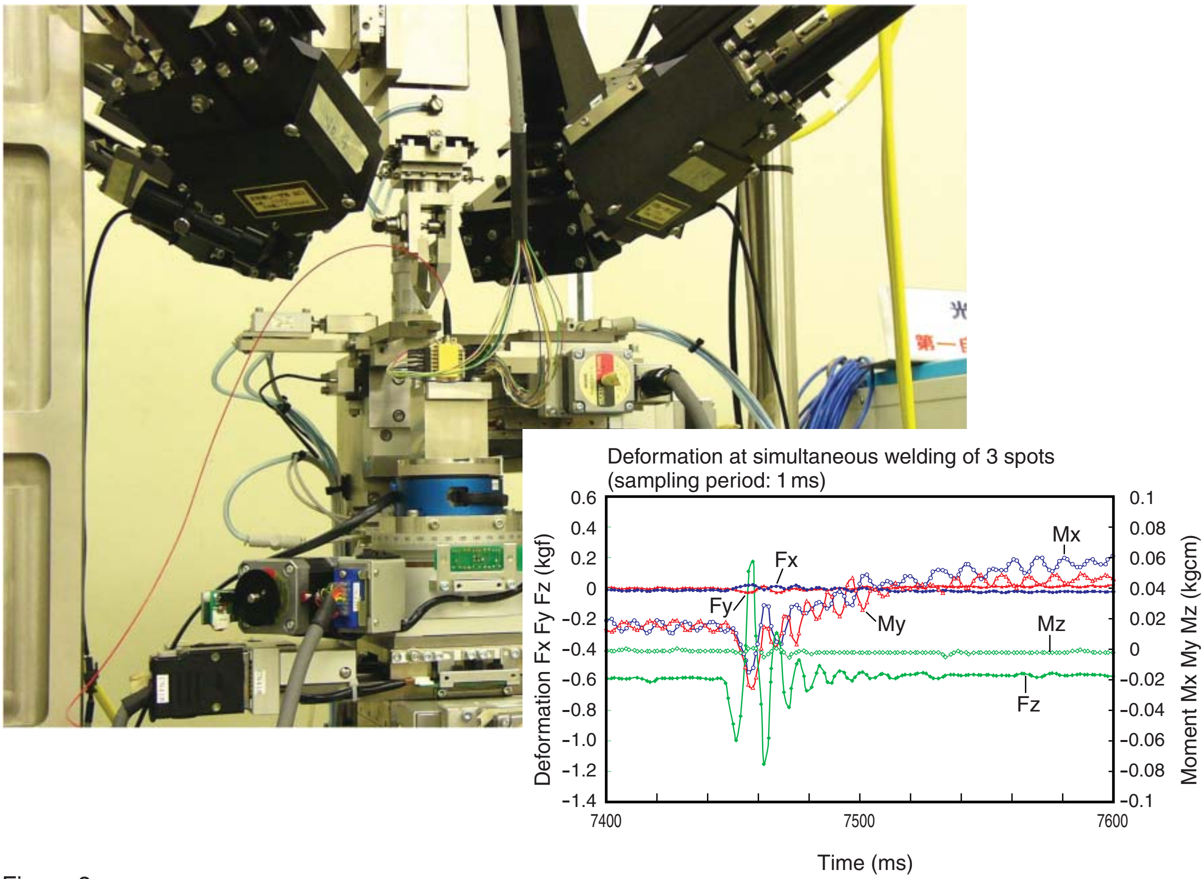
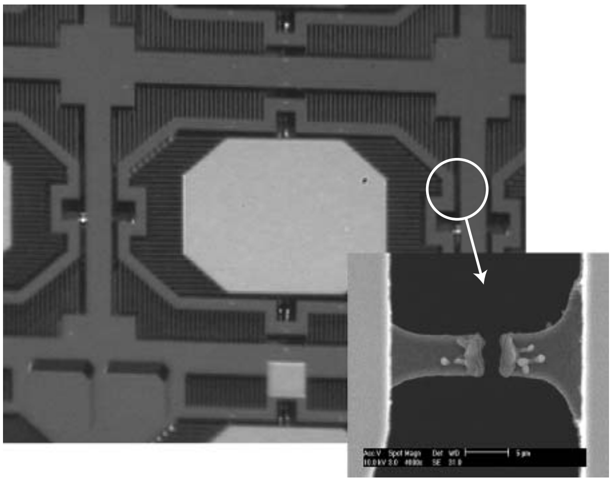


Figure 3
In-process monitoring of deformation at laser welding.

systems (MEMS) is rapidly growing.[4] Laser machining is regarded as a major technology for producing MEMS devices, and technical development and mass-production of laser machining have actively been promoted. The main materials of these devices are silicon and glass. However, these materials are difficult to micro-machine, have a low machining efficiency, and are easily damaged by the stresses that occur in traditional machining processes. By selecting the appropriate wavelength, laser machining can be used to fabricate MEMS devices from a wide range of materials. **Figure 4** shows an example of laser machining applied to a MEMS optical mirror. MEMS elements produced using silicon micromachining can be destroyed by the impacts that occur during packaging. To avoid this problem, we secure the MEMS element using a support beam and then use a third-harmonic YAG laser (wavelength: 355 nm) to cut the support beam in the final stage with a cut width of only 4 to 5 µm.

Recently, anodic-bonded glass-silicon laminates and glass-silicon-glass laminates have been used to fabricate MEMS devices. We have developed a technique that can dice these laminates with a cutting street of several hundred µm. Light from a fundamental YAG laser (wavelength: 1.064 µm) is focused onto the surface of the silicon substrate to cut the laminate.[5] This technique enables low-impact dicing with no damage as an alternative to the existing dicing with grinding stones.

We will further develop this micro-laser machining technology to establish techniques for producing smaller, more advanced high-quality devices at low cost.



Enlarged view of support beam that has been cut

Figure 4
Laser cutting of support beam in MEMS device.

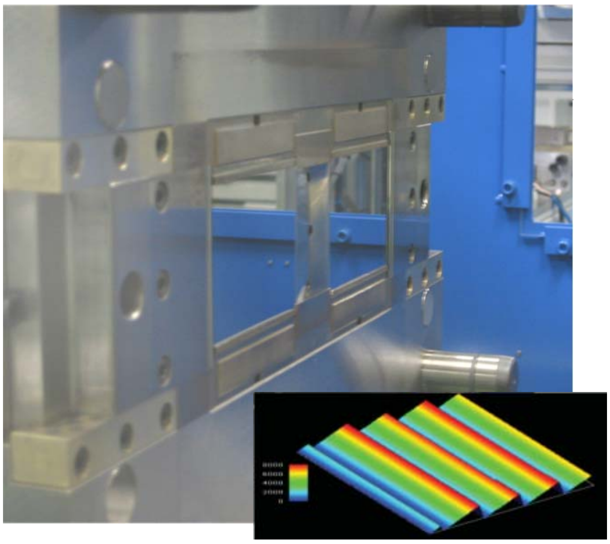


Figure 5
Appearance and prism pattern of metal mold for molding backlight guide plate.

4. Precision injection molding technology

The optical components of IT equipment, for example, the backlight guide plates of liquid crystal displays (LCDs), contain precision-machined plastic parts. Fujitsu is working on an ultra-precise metal molding technology to mass-produce plastic parts. This section describes an ultra-precise metal molding technology for producing LCD backlight guide plates and how computer aided engineering (CAE) for injection molding is applied to precision molding.

4.1 Development of ultra-precise metal molding technique

The LCD backlight guide plate is made of a transparent plastic such as acryl resin. It has a fine prism pattern of about 5 to 30 µm deep and a pitch of about 30 to 200 µm. The prism pattern controls the internal reflection and output angle of the light that travels through the backlight guide plate to the facing surface of the LCD panel. We are currently developing a technique for machining the metal mold used for injection molding of the fine prism pattern. This technique will enable us to mold a prism plane having a surface roughness of less than Ra 2 to 5 nm (**Figure 5**).

We have also developed metal molds that can withstand the high temperature and pyrolysis gas produced during molding while keeping the precise shape and surface roughness. These molds are manufactured as follows: 1) highly-polished stainless steel is plated with electroless nickel about 300 to 500 µm thick, 2) the molds are machined using a single-crystal diamond tool having a triangular cross-section. These molds require a considerable amount of cutting; for example, a mold for a 10-inch LCD backlight guide plate of a notebook PC has a cutting length of more than 1 km. Therefore, for molds for large backlight guide plates, we developed a special electroless nickel plating process so the mold can be free cut to extend the life of the diamond tool.

Furthermore, because of the rapid growth of ubiquitous computing, it is becoming important to reduce the power consumption of LCD backlights by improving output efficiency and equalizing luminance distribution. Fujitsu is developing a technique for machining a finer, more precise prism pattern on these molds and giving them an adjustable surface.

To ensure the precise transcription and optical transparency of fine patterns in injection molding of optical components, Fujitsu is also developing a more advanced technique for controlling the metal mold temperature and other techniques, including techniques for assessing manufacturing conditions other than general molding conditions and taking measures to prevent the contamination of raw pellets and other problems.

4.2 Application of CAE for precision injection molding

In addition to the metal molding technology for precisely-machined optical parts and precision injection molding technology described above, we have developed a computer aided manufacturing (CAM) system for injection molding called MOLDEST.[6] MOLDEST is software that calculates the optimum conditions for mass-production injection molding from a product's computer aided design (CAD) shape data. MOLDEST enables users to reduce the trial molding work performed at the start of mass-production and check whether the molding conditions are satisfied before manufacturing metal molds. MOLDEST is based on the concept that the precision of resin flow analysis can be greatly improved if the viscosity characteristics of the molten resin can be set more precisely. Resin flow analysis is a CAE tool for injection monitoring. The data used for this analysis is obtained from pressure sensors built into the metal mold and molding machine (**Figure 6**).

We have established a technique for using a mass-production injection molding machine to measure the viscosity characteristics of resin. This technique makes it possible to estimate the

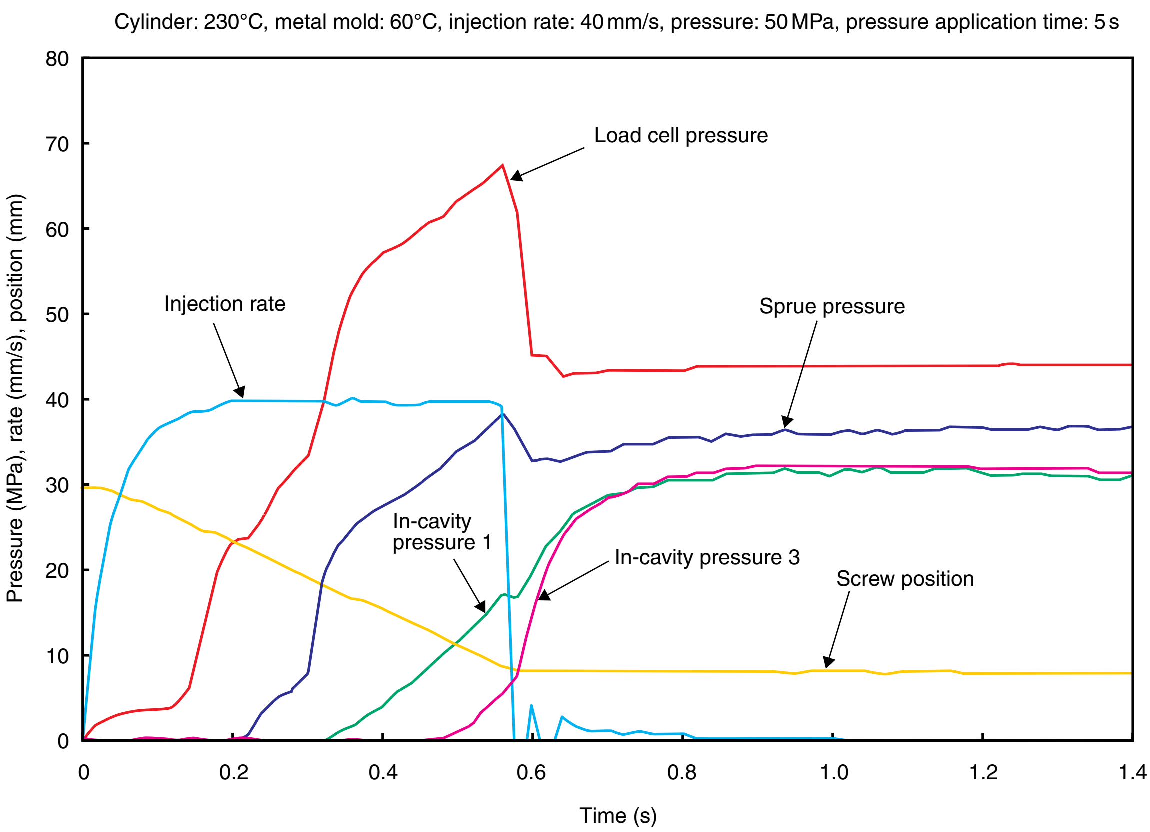


Figure 6
Monitoring of injection molding process.

viscosity characteristics in production conditions to a high degree of accuracy. Conventional CAE systems for injection molding can only be used for qualitative productivity evaluation; however, this technique makes it possible to use CAE systems for quantitative productivity evaluation. Moreover, the viscosity characteristic obtained using this technique can be used to obtain optimum injection pressure profile data. High-quality molding can be achieved simply by transferring the results to a pressure wave tracking type of injection molding machine.

5. Elaborate press forming technology

Fujitsu has cultivated an elaborate press forming technology through its production of high-precision pressed parts for IT equipment, for example, magnetic head suspensions for magnetic disk devices and ink jet nozzles for ink jet printers. In recent years, elaborate press forming technology has been widely applied and regarded as a key technology in the IT solution business. This section describes an example of applying this technology to the production of automobile fuel injection nozzle plates that have been mass-produced in collaboration with the former Fujitsu Sinter Ltd. (now Suruga Seiki Co., Ltd.). The nozzle plates are mounted at the tip of the fuel injection nozzle. Many holes, about the diameter of a human hair, are punched into 0.1 mm stainless steel nozzle plate at an angle of 20 degrees in two directions. To ensure the correct flow rate and injection angle, the nozzle plate requires a high machining precision.

5.1 Development of oblique hole punching technique

Fujitsu has established a technique for punching oblique holes into metal sheets without needing to obliquely position them. In this technique, which assures good workability, a cam makes the punch move obliquely while the press moves up and down.

While conventional presses can make equally-spaced holes, a fuel-injection nozzle plate requires a minimum fracture surface where the hole axis is acute with respect to the plane of the plate and sharp edges around the holes to stabilize the injection performance. To achieve this, the clearances must be carefully balanced. Experienced engineers must make sub-micron adjustments to the punch and die to optimize the positions of shear and fracture surfaces. This oblique hole punching technique enables high-quality pressing that is difficult to achieve using conventional machining.

5.2 Development of tape lapping deburring technique

We have developed a tape lapping technique for removing the micron-size burrs that are formed during the oblique hole pressing of metal sheets described above. In this technique, the sheets are secured to a dual-axis rotary table and an abrasive tape is slowly fed to the sheets to remove the burrs. This technique makes it possible to remove burrs without deforming the hole edges.

Figure 7 shows an automobile fuel injection nozzle plate that has been machined with this technique.

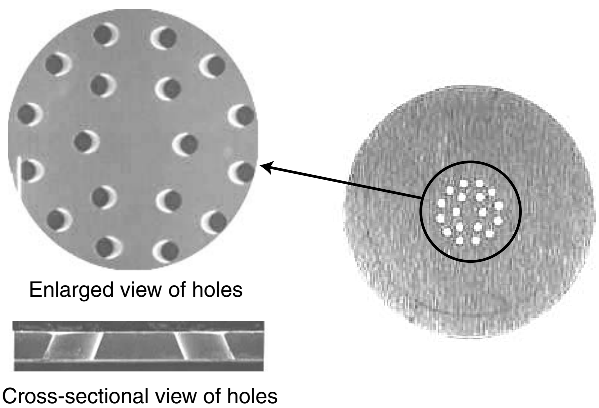


Figure 7
Automobile fuel injection nozzle plate.

5.3 Construction of mass-production line for rolled sheet metal

We constructed a compact mass-production line to punch oblique holes into rolled sheet metal that incorporates the techniques described above. The line is about eight meters long (**Figure 8**).

Process 1 (reference hole punching) cuts the sides of the material to straighten it and punches guide holes.

Process 2 (oblique hole punching 1) mounts a metal mold to punch multiple holes and moves the material at the XY stage to punch oblique holes one at a time. This process monitors whether the holes have been formed, and if it is detected that a hole has not been formed, the line is automatically stopped. The most likely cause for unformed holes is a broken punch.

Process 3 (oblique hole punching 2) punches oblique holes on the opposite side in the same manner as in Process 2.

Process 4 (defect removal) detects the occasional cases when the metal that has been punched is not fully separated from the metal sheet (i.e., it remains in the hole or is outside the hole but still attached) and removes the defective part without stopping the line.

Figure 8
Mass-production line for automobile fuel injection nozzle plate.

Functions have been added to continuously monitor the line in each process and notify the staff of problems by sending emails to their mobile phones. These enhancements have established a quick feedback system to maintain the metal mold and line.

The line has a production capability of 800 000 products per month and can operate unattended continuously for up to 80 hours.

We are currently developing a technique for machining all-shear-surface nozzles to produce a fracture-free surface for more stable fuel injection and multidirectional nozzles with a large spread of injection angles. We are also developing a technique for manufacturing all-shear-surface nozzles having tapered holes.

The elaborate press forming technology has been applied to the production of automobile fuel injection nozzle plates. The difficulty of machining fuel injection nozzles is increasing because of the growing demands for higher fuel efficiency and cleaner gas emissions. We will therefore further develop our elaborate press forming technology to satisfy these demands. Moreover, the techniques obtained in our production activities based on elaborate press forming technology will be applied to the production of precise mechanical components for MEMS devices and other IT equipment.

6. Conclusion

This paper described Fujitsu's approaches to elaborate, precision machining technologies. Manufacturing activities in Japan must be consolidated under the ongoing China-centric manufacturing circumstances. We will further improve these technologies to produce higher value at lower costs. Especially, we will focus on nanotechnology-based production techniques as key areas and promote the development of processes and facilities.

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