Application of Machine Learning to Laser Processing System and Latest Processing Technique

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1. Introduction

Two-dimensional laser processing systems have become indispensable machine tools at manufacturing sites thanks to dramatic technical progress, while rapid advances in processing techniques have expanded the scope of cutting.

However, in service environments, processing may stop due to differences in the quality of materials used, degradation of consumables, and other reasons, reducing the operating rates of laser processing systems. In addition, in recent years, the number of skilled workers who have a thorough knowledge of laser processing and how to operate processing systems has been decreasing due to the shrinking workforce and aging population. Accordingly, laser processing systems that offer higher productivity without depending on skilled workers are needed.

To satisfy such market needs, Mitsubishi Electric Corporation has developed a two-dimensional fiber laser processing system, GX–F, which provides sophisticated automation solutions.

This paper describes an AI technology incorporated into the GX–F and the latest processing techniques that were made possible by a new type of oscillator and AGR–eco.

2. External Shape of the Package

Main Specifications of the GX–F Series and Development Concept

Table 1 lists the main specifications of the GX–F. Its concept is a "non-stop processing" system. The GX–F offers a higher operating rate thanks to its AI functions, which the former ML3015eX–F Series did not have, and also higher productivity thanks to a new type of oscillator and AGR–eco, as well as lower running cost.

3. Application of AI to laser Processing Systems

In laser processing, the machining head concentrates the light emitted from the laser oscillator and radiates it to the target to be processed. When laser light is radiated to the target metal, assist gas is released from the nozzle at the end of the machining head and the target is processed at a constant speed. Cutting is performed based on processing conditions defined by various parameters. Standard processing conditions based on material quality and thickness are provided as settings for processing systems. If the processing conditions become unsuitable for the targets due to heat accumulated during the processing or if the nozzle gets damaged by spatters, etc. during the processing, processing defects can occur. To prevent these problems and maintain productivity, operators used to check targets during processing, correct the processing conditions according to circumstances based on their knowledge and experience, periodically check the appearance of the nozzles, and replace them.

For the GX–F, the following functions were developed: an AI assist function that judges whether processing can be accepted or not and automatically corrects processing conditions, and an AI nozzle monitoring function that judges the status of the processing nozzles and automatically replaces them when needed.

Table 1 Specifications of ML3015GX–F

Item		New model ML3015GX–F	Former model ML3015eX–F
Movement method		Optical scanning	
Fast feed speed (m/min)		Synthetic rate: 170	Synthetic rate: 140
Acceleration		XY:1.5G Z:1.5G	XY:1.0G Z:1.5G
Stroke (mm)	X-axis	3100	
	Y-axis	1550	
	Z-axis	120	150

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3.1 AI assist function

The AI assist function judges whether processing can be accepted or not based on the light and sound emitted during processing and automatically corrects the processing conditions. When this function is enabled and the processing is judged as proper, the processing speed is corrected so as to increase the productivity. Meanwhile, when the processing is judged as improper, the function automatically cleans or replaces the nozzle and feeds back information to the processing conditions to reduce processing defects and processing stoppages (Fig. 1).

For the AI assist function, a machine learning technique of supervised learning was adopted. The AI has learned a large volume of data on proper processing and various improper processing results for each thickness of sheet to be processed that were obtained in advance. The AI assist function consists of two types of AI: one to judge whether processing is acceptable or not based on the light emitted during the processing, and another to judge whether processing is acceptable or not based on the sound emitted during the processing. The judgment results are combined to output the final evaluation value. The discriminator of the AI that makes judgments based on light uses deep learning, while the discriminator of the other AI that makes judgments based on sound uses a mixture Gaussian model (Fig. 2).

3.2 AI nozzle monitoring function

The AI nozzle monitoring function automatically judges the status of a nozzle and if it has damage that affects the processing, the function automatically replaces it. This replacement and inspection of nozzles reduces processing defects and also reduces the changeover time by operators. When this function is enabled, the diagnosis is performed in the following processing flow: (1) the camera in the processing system photographs the nozzle, (2) the photo is cut (processed), and (3) the learned model is read to allow the AI to diagnose the nozzle.

For the AI nozzle monitoring function, a machine learning technique of supervised learning (classification) was adopted. The AI has learned proper nozzles and damaged (defective) nozzles based on actual photos. The AI's discriminator uses a convolutional neural network (CNN), which is a neural network dedicated to images. The diagnosis result is output as a score (0: normal, 1: abnormal).

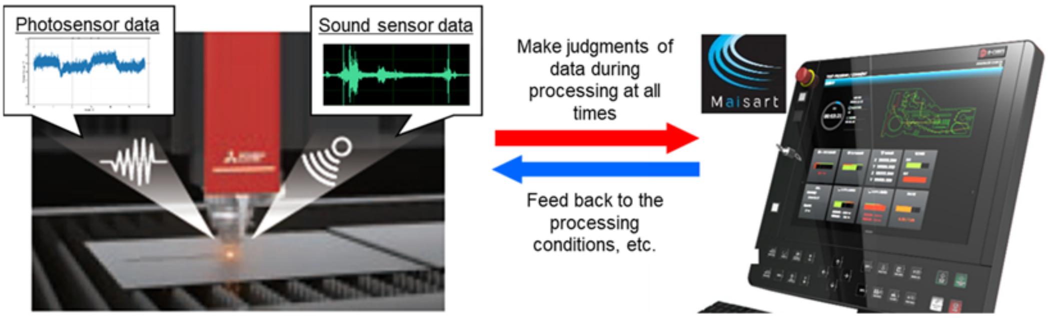

Fig. 1 Anomaly detection of laser-processing with machine learning

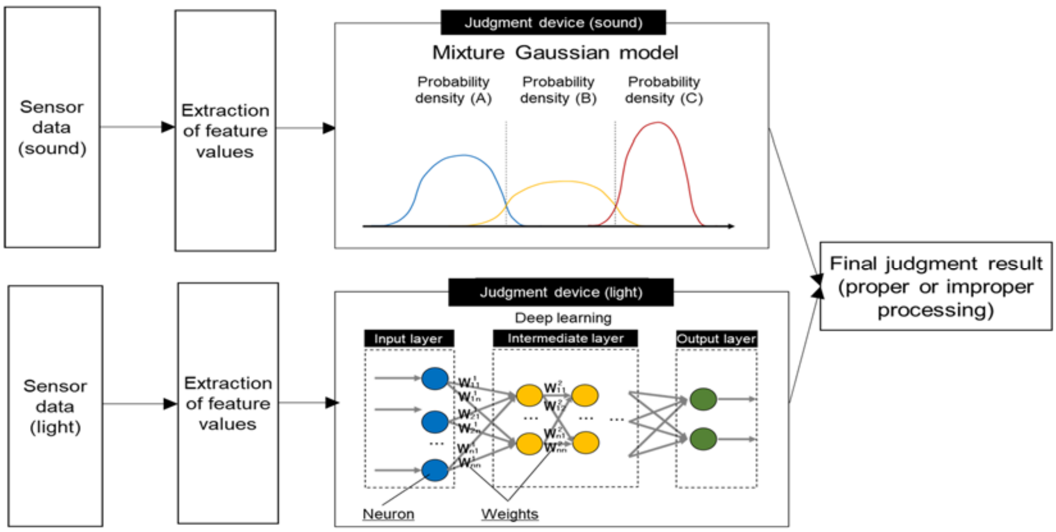

Fig. 2 Detection flow from the sensor data

Figure 3 shows a section that the CNN regarded as important (judgment basis) when calculating the score, visualized as a heat map by gradient-weighted class activation mapping (Grad-CAM). The white hazy section is the part that the CNN judged as important. To prevent CNN's judgment sections from deviating from those by humans, the discriminator was adjusted and the volume of data was increased, thus attaining a level that allows commercialization.

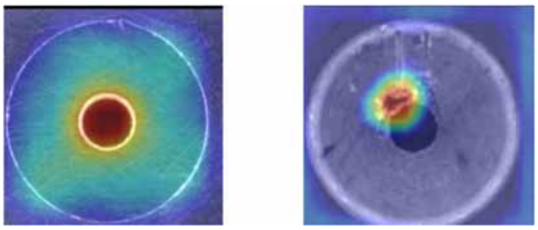

Fig. 3 Anomaly detection of laser processing nozzle (Visualization of feature by Grad-CAM)

3.3 Improvement in processing stability by AI technology

When the surface conditions of materials tend to cause processing defects, such defects occur at high frequency and it takes many hours for rework after the processing. In addition, the nozzle may get damaged during processing, further increasing the ratio of processing defects.

Figure 4 compares the simulated results of processing stability when the AI technology was applied and when not applied. The time was calculated from the estimated processing time. When the AI was applied, even when the surface conditions of the materials were not good, the AI assist function reduced the processing speed, greatly reducing the occurrence of processing defects. Although this reduction in speed increases the cutting time, after-treatment is unnecessary and so the total productivity increases. In addition, when processing defects occur due to nozzle damage, the AI assist function can detect the defects and the AI nozzle monitoring function can replace the nozzle automatically, thus improving the processing stability remarkably.

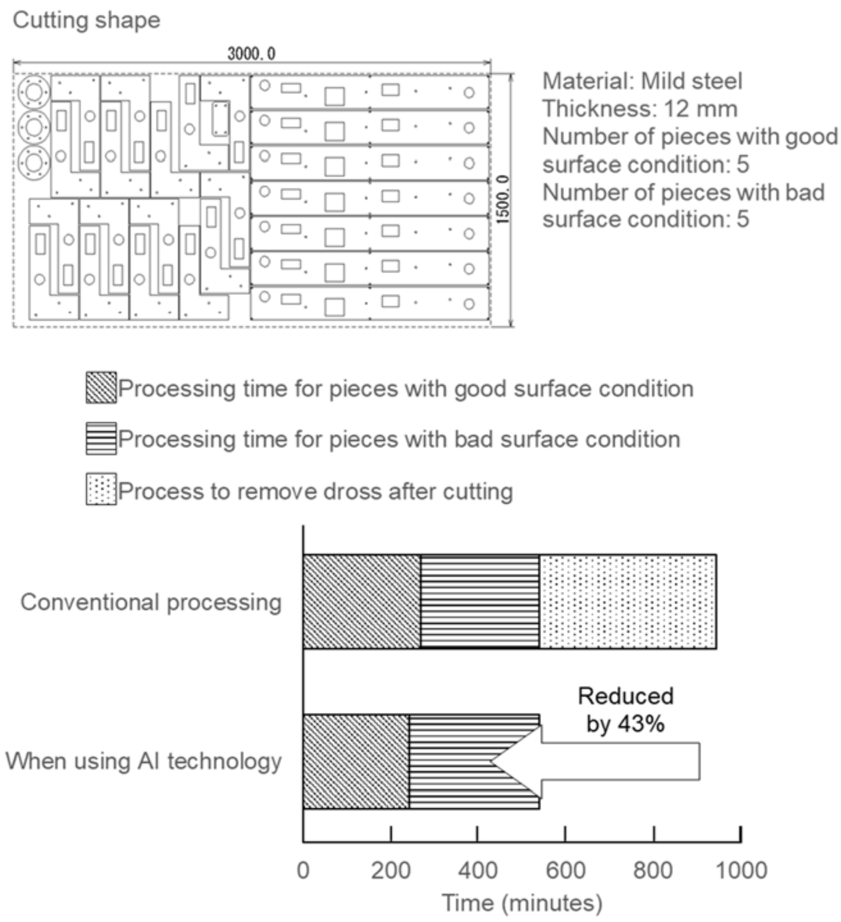

Fig. 4 Highly stable laser processing by AI technology

4. Latest Processing Techniques

The above section mainly described the AI technology used in the GX–F. In addition to higher processing stability, the processing capability of the GX–F has also been improved thanks to a new type of oscillator and gas flow control technology, AGR–eco. This section describes the latest processing techniques in detail.(1)

4.1 High-speed piercing of mild steel plates

In oxygen processing of mild steel plates with medium thickness or thicker, it takes longer to pierce them (boring before cutting) and the piercing time accounts for a large portion of the total processing time. When there are many holes to be bored and thus many piercing times, the ratio further increases. Consequently, it is important to reduce the piercing time to increase the productivity.

For the GX–F, the high responsivity of the new type of oscillator and a technology for high-speed beam control by zoom heads reduce the piercing time remarkably. When 25-mm-thick mild steel was pierced, the piercing time was reduced by 77% from the conventional time to 0.8 seconds (Fig. 5).

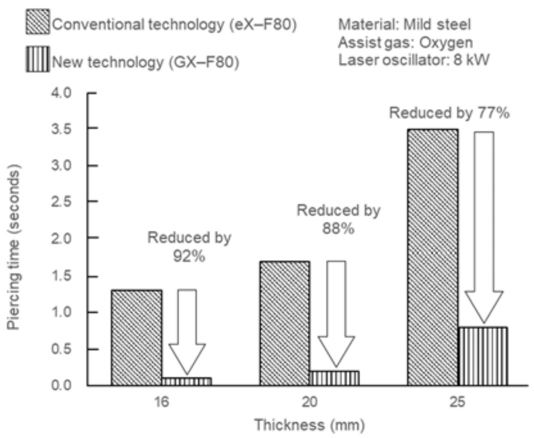

Fig. 5 Piercing time of mild steel

Fig. 6 Small hole processing of 25-mm-thick mild steel

4.2 Higher small-hole boring performance

To process plates, plasma cutting and gas cutting machines are generally used in addition to laser processing systems. However, the cutting width of plasma cutting and gas cutting machines is large and the thickness of materials to be cut is the rough minimum diameter of processible holes. For example, when 25-mm-thick mild steel is processed, the minimum diameter of processible holes is approximately 25 mm. Therefore, to process small holes, boring by machining is required after the cutting process. In contrast, laser processing in which concentrated laser beams are used for processing can bore small holes. However, the material melted during piercing builds up near the processed section and abnormal combustion occurs due to heat input during processing. This makes it difficult to bore small holes smaller than approximately half of the thickness. The small-hole boring performance of the GX–F was further improved, surpassing the performance of plasma cutting and gas cutting machines. High-speed piercing of mild steel plates reduces the heat input at the machining point and also beam formation and gas flow control technologies optimized for small-hole boring are applied. These have made it possible to bore small holes with a diameter of 3 mm (smaller than one eighth of the thickness) in 25-mm-thick mild steel (Fig. 6).

4.3 Technology to reduce the running cost

During laser processing, assist gas is jetted out coaxially with the laser light. Assist gas is used to discharge heated and melted material from the cutting groove. Different gases (e.g., oxygen and nitrogen) are used depending on the purpose of processing and the application.

In recent years, the power of fiber lasers has been greatly increasing. By combining a high-power fiber laser with nitrogen as the assist gas, it is possible to greatly increase the processing speed. However, when using nitrogen gas for processing, the cost of the gas accounts

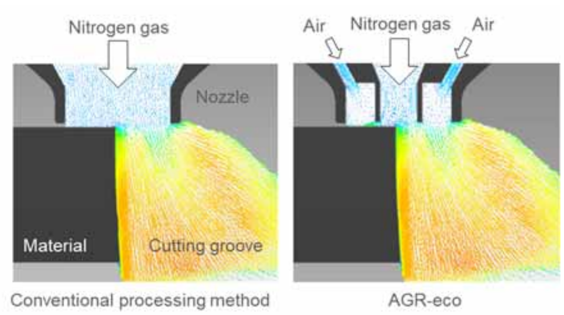

Fig. 7 Method of reducing nitrogen gas by AGR–eco

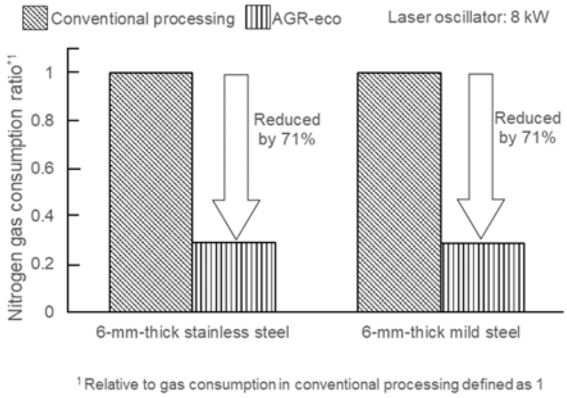

Fig. 8 Reduction of nitrogen gas by AGR–eco

Fig. 9 Cutting of pure copper with nitrogen by new oscillator

for a large portion of the running cost, which increases the production cost. In the GX–F, as shown in Fig. 7, nitrogen is supplied only to the area required to shield the machining point, and cheap air is used for the other sections. Thus, we have developed a gas flow control technology, AGR–eco, in which the consumption of nitrogen gas is greatly reduced while securing the function of the assist gas required to remove molten materials.

AGR–eco can be used to cut stainless steel and mild steel with nitrogen, and can be applied to sheets and plates as is the case with common laser processing. Figure 8 shows the reduction of nitrogen gas consumption by AGR–eco. Compared to the conventional processing method, the nitrogen consumption is reduced by 71% for 6-mm-thick mild steel and 6-mm-thick stainless steel.

4.4 Cutting of pure copper with nitrogen

To cut copper, which is a highly reflective material, with a fiber laser, oxygen and air need to be used as assist gases in general. Meanwhile, machined copper parts are often used for electrical components and other similar parts. In such cases, the oxide film needs to be removed after cutting. Although using nitrogen can reduce oxidation on the cutting planes, light reflected from the machining point may damage the machining head and laser oscillator during the processing. To solve this problem, a new type of oscillator having a device to remove reflective light was developed and also nozzle cooling control was developed for the GX–F. As a result, pure copper can be cut with nitrogen, expanding the scope of application of laser processing (Fig. 9).

5. Conclusion

This paper described the AI technology and the latest processing techniques applied to the new type of fiber laser processing system, the ML3015GX–F Series. Technologies related to fiber laser processing systems have been rapidly advancing and will continue to do so in the future. In addition to improving the processing system performance, we will also focus on reducing non-processing time (e.g., changeover and sorting) and strive to satisfy various needs at production sites in order to support flexible production for our users.

References

(1) Yoshio S.: Mitsubishi Electric Corporation's Latest Laser Processing Techniques, Proceedings of the 84th Laser Materials Processing Conference, 139–144 (2016)