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ADVANCE

Factory Automation

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Changes for the Better

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Factory Automation

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Precis

In this issue, we will introduce what is necessary to evolve into a next-generation production system as Factory Automation (FA) beyond Digital Transformation (DX), as well as Mitsubishi Electric's wire laser metal 3D printers and industrial robot support services as examples of products and solutions that bring value to the FA field, such as improving productivity and achieving sustainability.

Overview

Author: *Tetsuo Sawaragi**

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Future FA beyond DX: Tacit Knowledge and Systemic Thinking

In the manufacturing workplace of the future, automation and robots will be increasingly introduced due to labor shortages caused by a decline in the working population, and it will be necessary to accommodate irregular work patterns and improve the Quality of Working Life (QoW) of field workers. We must reconsider the production site as a “socio-technical systems” in which human abilities, production equipment, and work environments are complexly intertwined. After such a reconsideration, it becomes possible to monitor the cycle time of each process, predict future dynamics and shorten cycle times by making appropriate line balance adjustments by constantly acquiring work data on lines where people and equipment collaborate. However, to achieve these objectives, we will need to build holistic models of work activities based on Digital Transformation (DX), and by using such models, allow the tacit knowledge of skilled managers to be brought to bear on line balance management. This is what is known as a “digital twin” of the production site, constructed in cyberspace based on data. The twin must be applied to on-site operations in combination with human wisdom. Through FA which integrates systemic concepts, while emphasizing harmony with DX, we will achieve evolution toward next-generation production systems that can match supply with demand.

Industrial Robot Support Service "iQ Care MELFA Support"

Authors: *Atsushi Oyama*, Shingo Chida**

**Nagoya Works*

Abstract

Production sites in the manufacturing industry have experienced labor shortages in recent years. To resolve this issue, the industry is adopting robots as automation, and there is a growing need for further productivity improvement and stable operation of production equipment.

Against this backdrop, we are offering after-sales service focusing on repair services for the "MELFA Series" of industrial robots from Mitsubishi Electric. The aim is to achieve stable operation of customer systems after purchase. However, needs for after-sales service are diversifying due to recent labor shortages, workstyle reform, and dissemination of the Internet of Things (IoT). In light of these conditions, we have developed new after-sales service products to meet customer needs.

1. Introduction

Needs for after-sales service of industrial robots are diverse and depend on factors like robot use methods and environments, maintenance costs, and approach to maintenance. There is also a need for more efficient service due to shorter working hours, driven by the labor shortages and workstyle reform of recent years.

To meet these needs for after-sales service of robots, we have developed a service that supports stable robot operation in all phases, including robot use, maintenance, and repair.

This paper describes features of the three sub-services making up this new "iQ Care MELFA Support" service: monitoring service, inspection service, and extended warranty service (Fig. 1).

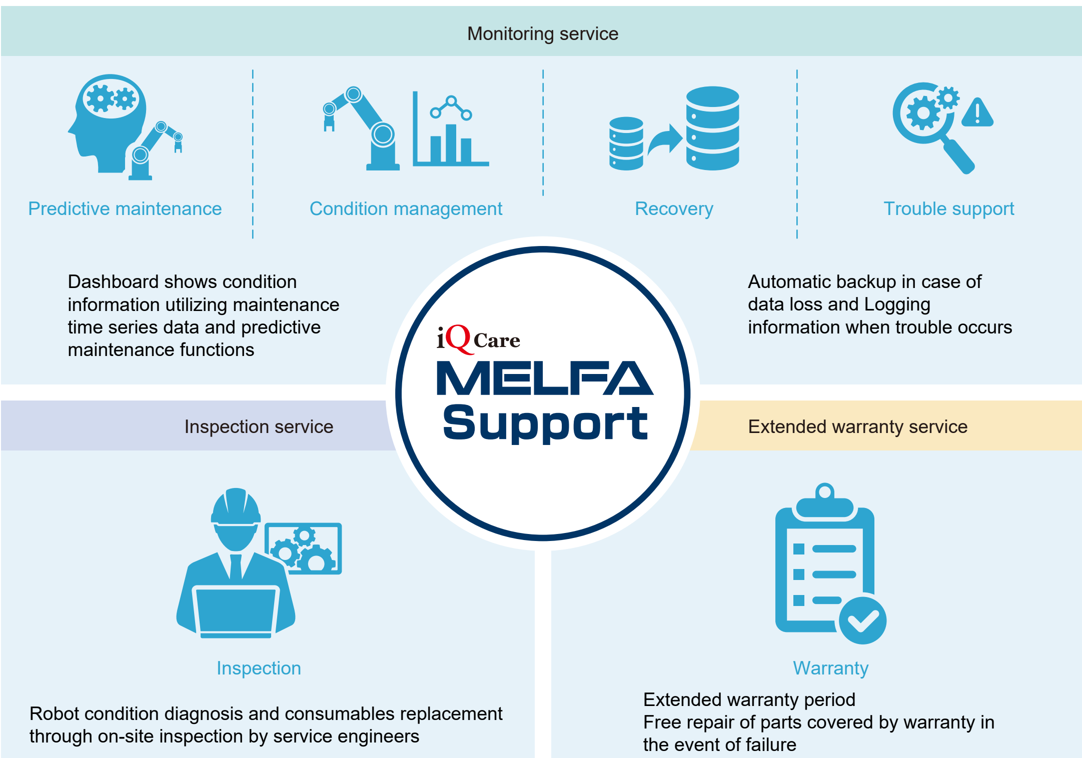


Fig. 1 iQ Care MELFA Support

2. iQ Care MELFA Support

iQ Care MELFA Support is an after-sales service product offering three services as a single package. These services can be used not only at startup when a system is first built, but also during actual system operation, and for malfunction repair and maintenance. The service is offered to customers who purchase new industrial robots from our company, and as an option to customers who have already adopted robot systems. Therefore, the service was developed to minimize the number of components, and enable operation without major changes in the existing system composition of the customer's operating environment.

With this service, various kinds of data are collected on a daily basis, such as operating information during system operation, and inspection information from maintenance or repair. This data increases in volume as the operating period grows longer. However, the CR800 robot controller used by the MELFA FR Series only has the minimal data storage area needed for operation, e.g., for the MELFA BASIC program for operating the robot, parameters for changing control settings, and alarm occurrence log data for a limited number of incidents. We have realized provision of services without reworking the customer's existing systems. This was achieved by using a special Secure Digital (SD) card that can be used for data storage as a key part, not just as a physical key for enabling the service.

The basic system configuration differs from the previous configuration of a robot arm (main unit), robot controller for controlling that arm, and engineering tools (RT ToolBox3) to support checking the robot state and doing programming. The adopted configuration is simple and involves merely inserting an SD card containing information for activating the service into the SD card slot that is standard equipment of the CR800 controller. The various types of information saved on the SD card are files of text data in Comma Separated Values (CSV) format, and this makes it easy to do secondary processing of data suited to the customer application. The system configuration is shown in Fig. 2.

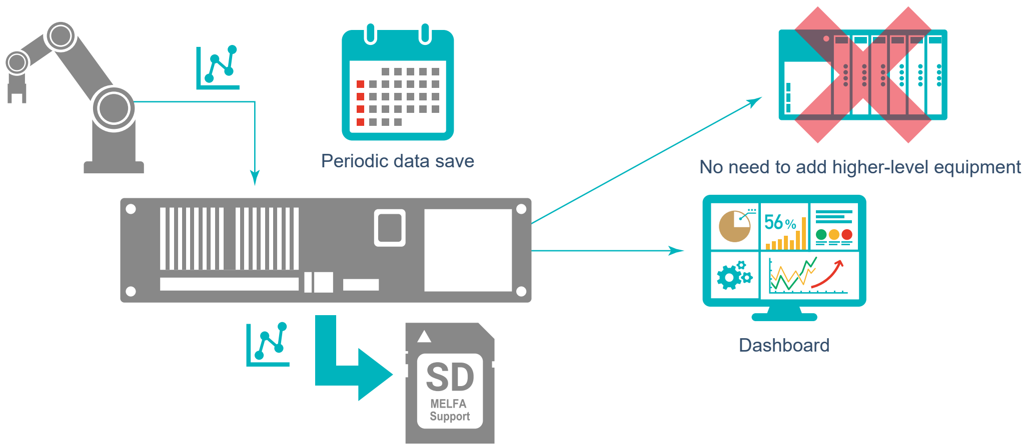


Fig. 2 System composition of iQ Care MELFA Support

3. Features of iQ Care MELFA Support

3.1 Monitoring service

The monitoring service provides a tabular dashboard display of various data from the robot that is necessary for stable operation, and thereby enables use of software for accessing and managing comprehensive maintenance information.

Digital management of operation/maintenance of FA devices is becoming increasingly sophisticated, in line with promotion of Digital Transformation (DX) in the manufacturing industry. As part of that trend, we have packaged multiple software functions together with the objective of digitally providing diverse operation data, covering both the existing customer segment currently using the robot system, and the new customer segment.

The basic function is "condition management." This involves automatic tabulation of day-to-day robot operating information, monitoring of daily operation information and the status of robot components, conversion of these to time series files, and saving on an SD card. However, additional functions are also provided that are useful to customers from the perspective of after-sales service.

The purpose of the recovery function is to perform daily backup of robot settings and stored programs, and allow the user to fix mistaken changes in settings and mistakes in program editing due to mis-operation.

Robot data is automatically backed up at a frequency of once a day, by saving onto an SD card. The date when backup data was saved can be accessed from the calendar displayed in RT ToolBox3, and the robot settings or program can be restored to their state on a previous day by selecting any save date (Fig. 3).

Fig. 3 Conceptual illustration of recovery function

The drive recorder function saves, as a log, servo data of the robot before and after a designated error, triggered by occurrence of that error at the robot being used (Fig. 4). When a problem occurs, this allows investigation of the cause of the error, including the state immediately before it occurred. This enables use as a cause analysis tool when a problem occurs that is very difficult to investigate.

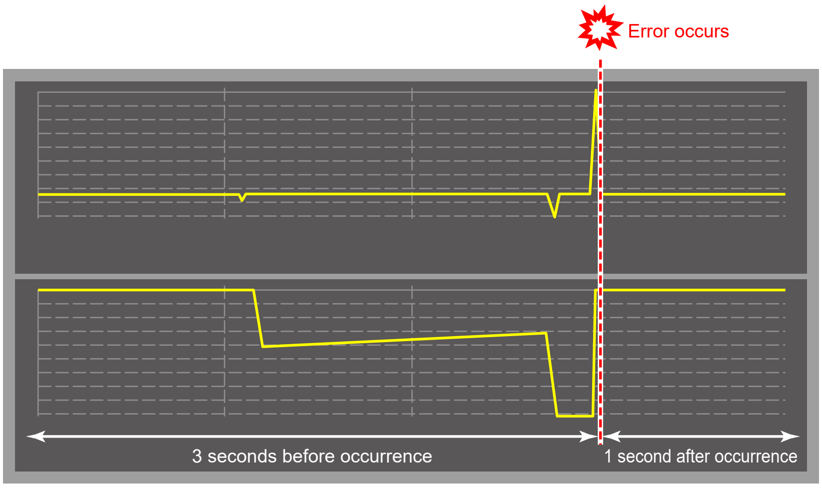


Fig. 4 Conceptual illustration of drive recorder

The predictive maintenance function enables reduction of downtime and projection of recommended times for maintenance through early detection of problems with robot components or signs of deterioration. This function enables use, within iQ Care MELFA Support, of AI functions that have earned a high reputation from the market as “MELFA Smart Plus”. To promote broader customer recognition of the predictive maintenance function, we have allowed it to be used for a limited time as part of iQ Care MELFA Support. The customer can continue using the function by entering into a continuation contract for each service of iQ Care MELFA Support, or purchasing MELFA Smart Plus.

Data produced by these functions is incorporated into files, and accumulated in the SD card. In RT ToolBox3, there is a tabular display of this data as a dashboard. This enables management of general maintenance information, and use of commercially-available tools such as Business Intelligence (BI) tools through secondary processing by the customer.

3.2 Inspection service

3.2.1 What is inspection service?

Inspection service is a service in which our service engineers visit the location where the industrial robots are installed, and carry out tasks such as diagnosing the conditions of the robots and replacing consumables.

Industrial robots are industrial equipment composed of many parts. Also required are periodic consumables such as backup batteries for the memory that stores the detector's locational information and lubricants (grease, etc.) associated with the operation of the drive units.

Therefore, maintenance based on periodic inspection is indispensable for stable operation of a robot. However, in analysis of market malfunctions, cases have been observed where periodic inspection was not done due to the trouble involved in maintenance, and as a result, sporadic malfunctions had an impact on production.

With this inspection service, our service engineers carry out periodic maintenance, and the customer's robots are kept in optimal condition, thereby ensuring stable robot operations.

3.2.2 Technical points for the inspection service

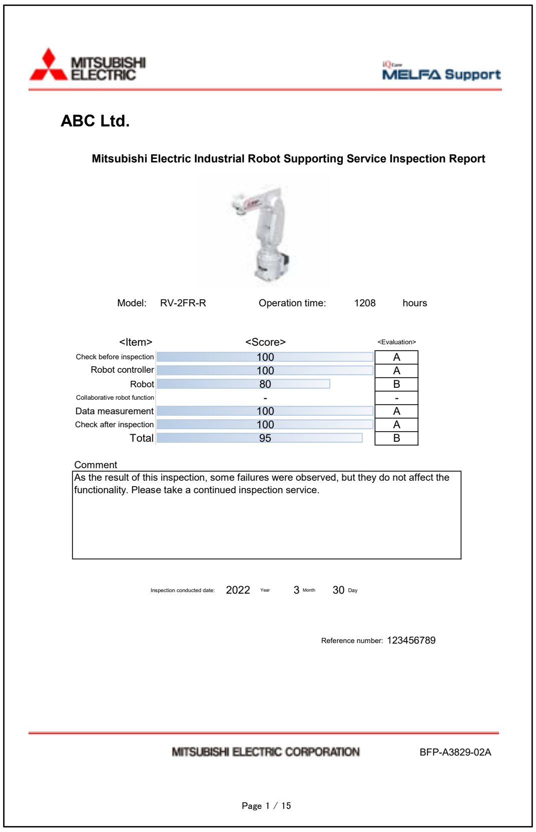
With previous inspection services, judgments were made based on the experience of the service engineer. For example, in judging backlash of a robot arm accompanying operation, the service engineer would set the robot to the servo lock state, and then check backlash based on his or her own "feel" to determine whether it was abnormal. This method allows judgment by service engineers with extensive experience, but cases arise where a decision is difficult for service engineers with little experience.

Therefore, inspection was switched to a method enabling quantitative judgment based on numerical values obtained using measuring instruments, etc.

Also, during inspection, the service engineer previously had the task of visually checking internal data accumulated in the robot controller (e.g., condition information) and transcribing it, etc. Therefore, with this inspection service, work time was shortened and transcription errors prevented by developing software for automatically converting internal data. The FR Series shown in Fig. 5 is an example of a robot covered by this service.

Fig. 5 Example of applicable robot (FR Series)

Results of judgment of the robot state based on this change in the inspection method are presented to the customer through an inspection report, like that shown in Fig. 6. With this inspection service, the various inspection items are classified, and judgment values are established for each classification. This enables judgment at a glance of normal/abnormal status for each inspection item.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iQ Care MELFA Support

ABC Ltd.

Mitsubishi Electric Industrial Robot Supporting Service Inspection Report

Model: RV-2FR-R Operation time: 1208 hours

<Item>	<Score>	<Evaluation>
Check before inspection	100	A
Robot controller	100	A
Robot	80	B
Collaborative robot function	-	-
Data measurement	100	A
Check after inspection	100	A
Total	95	B

Comment

As the result of this inspection, some failures were observed, but they do not affect the functionality. Please take a continued inspection service.

Inspection conducted date: 2022 Year 3 Month 30 Day

Reference number: 123456789

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Fig. 6 iQ Care MELFA Support inspection report

3.3 Extended warranty service

3.3.1 What is extended warranty service?

Extended warranty service extends the warranty period associated with the product. Previously, the warranty for our company's robots was only valid for one year after purchase of the product. The warranty provided repair at no charge for malfunctions during the warranty period. However, there were issues for end users such as prediction of maintenance costs after equipment adoption, and warranty expiration at the time of equipment delivery due to the startup period at the system integrator.

Extended warranty service solves these customer issues by further extending the one-year warranty period that comes with the product. Customers who have already purchased equipment are also eligible for extended warranty service, provided no problems are identified in the standardized, quantified inspection service described in section 3.2. This will allow us to support more customers. An overview of the service is shown in Fig. 7.

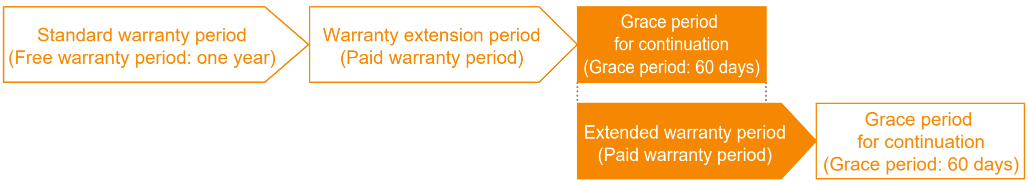


Fig. 7 Extended warranty service

3.3.2 Technical points for the extended warranty service

Because this service extends the warranty period, it is necessary to accurately ascertain the use period of the robot to which it is applied. It must also be ensured that information relating to the use period cannot be easily changed. With this service, information on the robot to which the service is applied, and the robot's use time information, are managed as data that cannot be accessed by the user. This is done by using a special hidden information area on the SD card. Data in this area can only be accessed by special processing incorporated into the firmware of the CR800 controller, or applications created using the

Software Development Kit (SDK) provided by the SD card manufacturer. It cannot be changed with publicly available information. Also, if robot setting information is changed to an abnormal value relative to the use period information saved in this area, then processing is performed to disable the function and temporarily stop the service.

4. Conclusion

This paper has described the features of iQ Care MELFA Support. This support has been developed as an after-sales service product to promote stable operation of customer equipment in the industrial robot MELFA Series.

Going forward, market requirements will likely continue to diversify for robot products, for which there is a growing need for higher productivity and stable operation as production equipment. Therefore, we anticipate that requirements for after-sales service will also become more diverse, and we will continue to expand the content of the service in the future, developing service measures to address customer needs.

Wire-Laser Metal 3D Printer AZ600

Authors: *Maiku Hayashi*, Nobuyuki Sumi**

** Industrial Mechatronics Systems Works*

Abstract

Additive Manufacturing (AM, 3D printing) is seeing broader application in the manufacturing industry.

Mitsubishi Electric has developed the wire-laser metal 3D printer "AZ600," which is the first in Japan[*1] to adopt a combination of metal wire and laser as a material and a heat source respectively. The AZ600 is equipped with an AM process control function that detects the printing status using various sensors and coordinates machining conditions and axis speeds, achieving stable printing and high precision. Furthermore, by using Mitsubishi Electric's unique dot forming, it is possible to suppress thermal distortion and oxidation. In cases where AZ600 is applied to AM, processing time, manufacturing costs, and material waste can be expected to be reduced, contributing to carbon neutrality. Furthermore, we can expect more stable quality in work dependent on individuals, and better response to needs for automation and labor-saving.

1. Introduction

In recent years, the manufacturing industry has experienced soaring raw material prices and longer delivery times due to COVID-19 outbreaks and growing geopolitical risks. Carbon neutrality has also garnered increasing attention in countries worldwide. Since AM can finish materials in near-net shape (a state close to that of a finished product), it is expected to reduce costs by reducing waste materials, shorten delivery times, and reduce energy consumption. Furthermore, there is a design method specifically for AM called Design for Additive Manufacturing (DfAM), and this makes maximal use of the characteristics of AM. If this type of design is used, we can achieve higher functionality as well as conserve resources. In AM, printing is done using digital data, such as 3D-CAD data. This is a digital manufacturing technology that enables printing by anyone, anywhere, provided they have the equipment and necessary processing conditions. As a result, the technique is also garnering attention as a technology for realizing Digital Transformation (DX).

We developed the wire-laser metal 3D printer AZ600 against this backdrop. This system can contribute greatly to society through AM manufacturing—from solving production problems to protecting the environment. The Directed Energy Deposition (DED) method combines metal wire (material) and a laser (heat source), and this has various advantages for the user. However, the method requires development of very difficult control mechanisms, so only certain equipment manufacturers can enter the field. We have realized a wire-laser metal 3D printer for the first time in Japan[*1]. This was achieved by leveraging the technical synergy of our company's products: Computerized Numerical Control (CNC), laser machining equipment, and wire electric discharge machining equipment. The AZ600 first went on sale in the Japanese market in March 2022.

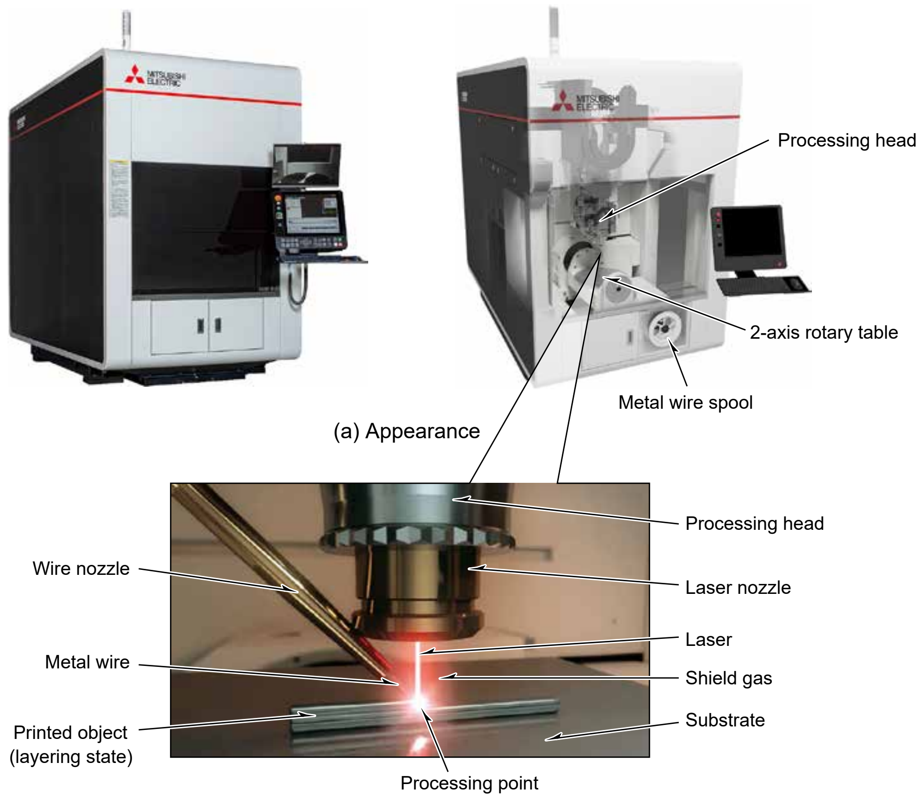
2. Features of the Wire-Laser Metal 3D Printer AZ600

2.1 Equipment specifications

Appearance of the AZ600 is shown in Fig. 1(a), and specifications are given in Table 1. DED is used as the printing method. The system is equipped with three Cartesian axes (XYZ) on the processing head side, and two rotary table axes (incline axis and rotation axis) on the workpiece side. Simultaneous 5-axis control is performed using CNC made by our company. This enables stable no-drip printing by varying orientation on the workpiece side, even with shapes that have complex curved surfaces or overhangs. As the heat source laser, the system is equipped with a continuous-wave type fiber laser oscillator, and models with two different outputs (2 kW and 4 kW) can be selected.

Figure 1(b) shows the situation near the processing point. The intersection of the perpendicularly irradiated laser and the metal wire supplied from the wire nozzle becomes the processing point. At the

*1 According to our research, February 24, 2022 processing point, integrated metal is produced by simultaneous fusing of the substrate and metal wire while suppressing oxidation with a shield gas (argon) supplied coaxially with the laser. Commercial φ1.2mm welding wire can be used as the metal wire. Replacement work has been made safer and more efficient by setting the metal wire spool at the worker's feet.



(a) Appearance

(b) Conditions near the processing point during AM printing

Fig. 1 Metal 3D printer AZ600

Table 1. Specifications of metal 3D printer AZ600

Printing method		DED
Supplied material		Metal wire (standard diameter: φ1.2mm)
Heat source		Fiber laser (CW)
Laser rated output		2kW or 4kW
Outer form	Width × Depth × Height (mm)	1,600 × 2,900 × 2,500
	Main unit weight (kg)	Approx. 7,000
Axis movement range	X × Y × Z-axis (mm)	600 × 600 × 600
	B(A)-axis (°)	±120
	C-axis (°)	360
Workpiece	Maximum size (mm)	500 × 500 × 500 (φ500 × 500)
	Maximum weight (kg)	500

Use of wire as the supplied material enables cleaner and safer material handling than powder methods. Printing yield is higher, and probability of producing air holes in the printed object is low(1). Material switching is also comparatively easy.

By using a laser as the heat source, printing can be done with higher precision than with the arcs and electron beams used with other DED methods. There is also no need to provide a vacuum chamber, as in the case of an electron beam.

2.2 Monitoring function and AM process control function[2]

The processing head is equipped with sensors and a camera. It monitors things like height on the workpiece side, and status of the molten pool formed at the processing point, and a display is provided on the equipment's operation screen. Also, the CNC is equipped with a function for controlling the printing process (Fig. 2). With this function, the previously described monitoring results are reflected in axis movement commands by the Numerical Control (NC) program, and the initial output command for processing conditions (i.e., laser output and feeding speed). Also, axis movement commands and processing condition output commands are performed by coordinating axis movement control, laser output control, and wire feeding control so that factors like wire end position, bead width, and bead height are appropriately maintained during printing. In this way, we strive for greater stability in the printing process, and greater precision of the printed article.

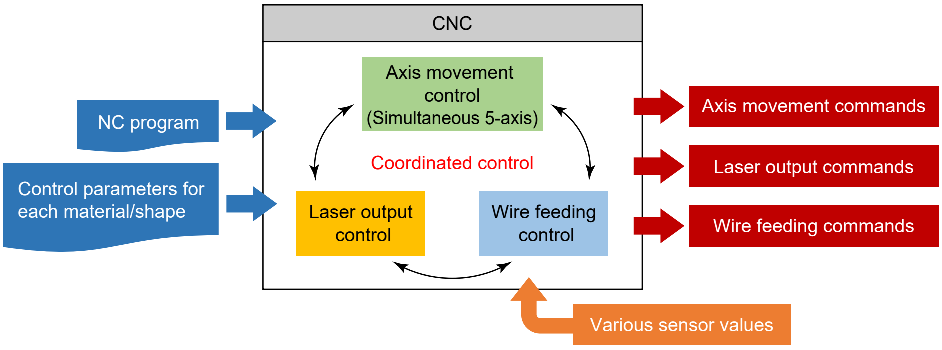


Fig. 2 AM process control function

2.3 Printing processes: "Line forming and dot forming"

This equipment is capable of dot forming[3], where a dot-shaped bead is formed by performing wire feeding and laser irradiation in a pulsed fashion. Figure 3 shows the printing process for one layer with the ordinary line forming process and the dot forming process. The printed object is formed in three dimensions by stacking and lining up these layers.

In line forming, a line-shaped bead is formed in a single layer by continuously performing laser irradiation, wire feeding, and axis movement, as indicated in Fig. 3(a).

In dot forming, on the other hand, a dot-shaped bead is formed by performing laser irradiation and wire feeding for just the specified time while axis movement is stopped, as indicated in Fig. 3(b). After that, the system moves axes to the next position designated by the NC program, and a dot-shaped bead is formed again by the same process. A single layer is formed by repeating this process.

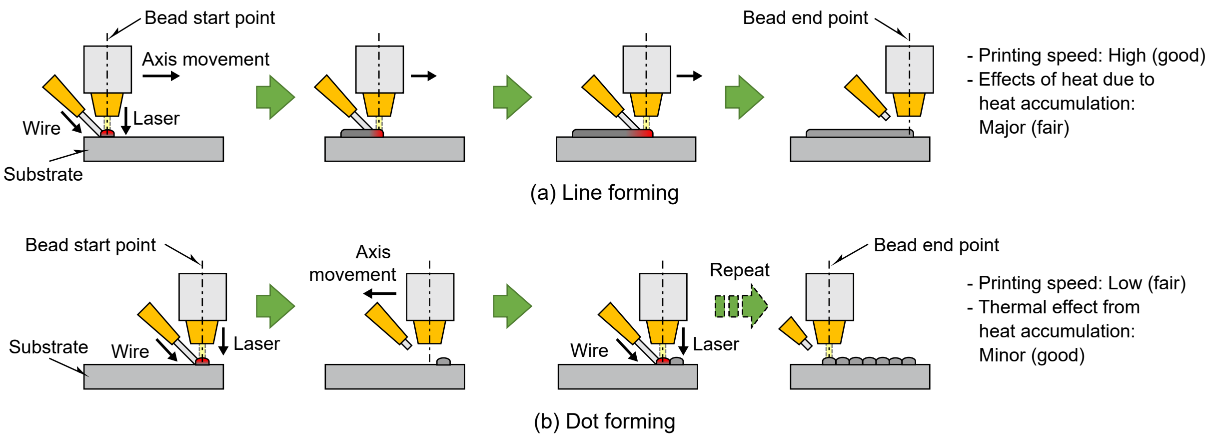


Fig. 3 Schematic diagrams of single-layer printing

In line forming, heat input per unit time is higher than dot forming, so there are cases where significant heat accumulates, and printing precision drops due to thermal strain. However, line forming has the advantage that printing speed is high.

On the other hand, although dot forming is slower than line forming, there is little thermal strain on the printed article due to heat accumulation, and printing precision is high. It is also possible to lengthen the shield time at the processing point, and thus printing can be done while suppressing oxidation, even with materials averse to oxidation like titanium alloy.

Printing is done by selectively using line and dot forming to suit the printed shape, printing location, and required quality, based on the characteristics of each printing process.

3. Effects of Use

3.1 Near-net-shape

Figure 4 shows an example of using near-net-shape for a marine propeller. Additive manufacturing of the blade part is done via line forming and dot forming, using stainless steel 17-4PH wire, on a base consisting of a φ99mm cylinder made of stainless steel 304. The cylinder base can also be fabricated by additive manufacturing, but in this case, fabrication can be done more quickly and inexpensively by lathe turning. Fully exploiting the advantages of AM, by skillfully combining with techniques other than AM in this way, is one element of DfAM for DED.

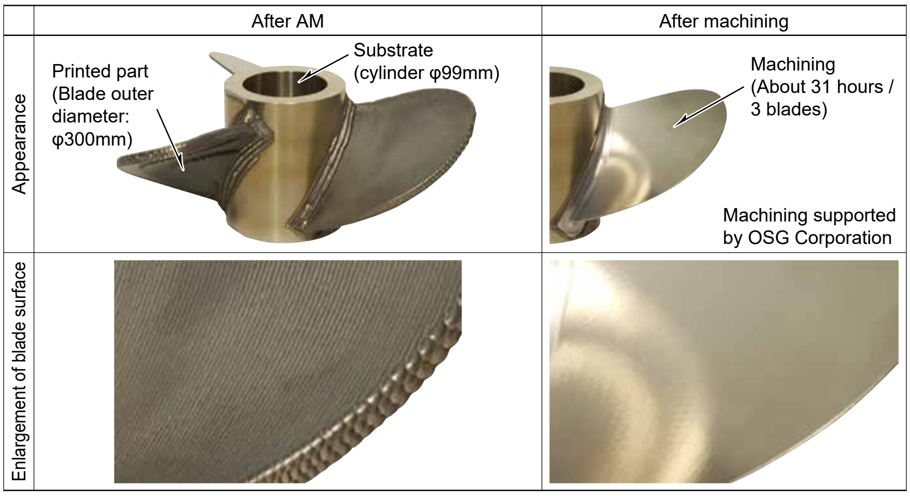


Fig. 4 Marine propeller produced using AM method

Outer diameter at the blade end is φ300mm, and printing time for a total of three blades is about 9 hours. Machining is done next, as the process after additive manufacturing, to achieve product precision. Machining time is about 31 hours for a total of three blades.

Figure 5 shows the results of comparing the conventional method (machining only) and the AM method (additive manufacturing + machining). Figure 5(a) shows a comparison of total processing time. The conventional method requires approximately 168 hours to process as it is machined from solid stainless steel 17-4PH with a diameter of 312mm. With the AM method, on the other hand, processing time can be greatly reduced by forming near-net-shape blades, and then doing finishing only (without rough machining) as the subsequent process. This method takes about 40 hours in total. By using additive manufacturing, processing time can be reduced by about 80% compared to the conventional method.

Next, Fig. 5(b) shows a comparison of the amount of material waste. With the conventional method, about 95% of the material becomes waste in the form of cutting chips. The AM method can reduce the amount of material waste by as much as 96.5% compared to the conventional method, and thus energy consumption can be curbed, helping to reduce carbon emissions.

Finally, Fig. 5(c) shows a comparison of manufacturing cost. The amount of material waste in Fig. 5(b) can be regarded as the amount of machining, and since stainless steel is a hard-to-machine material, machining must be done by consuming large amounts of comparatively-expensive end mills made of carbide, etc. The AM method, on the other hand, requires wire and shield gas as consumable supplies, but the amount of machining is reduced. Therefore, end mill consumption and material volume are decreased, and manufacturing costs can be reduced by 78%.

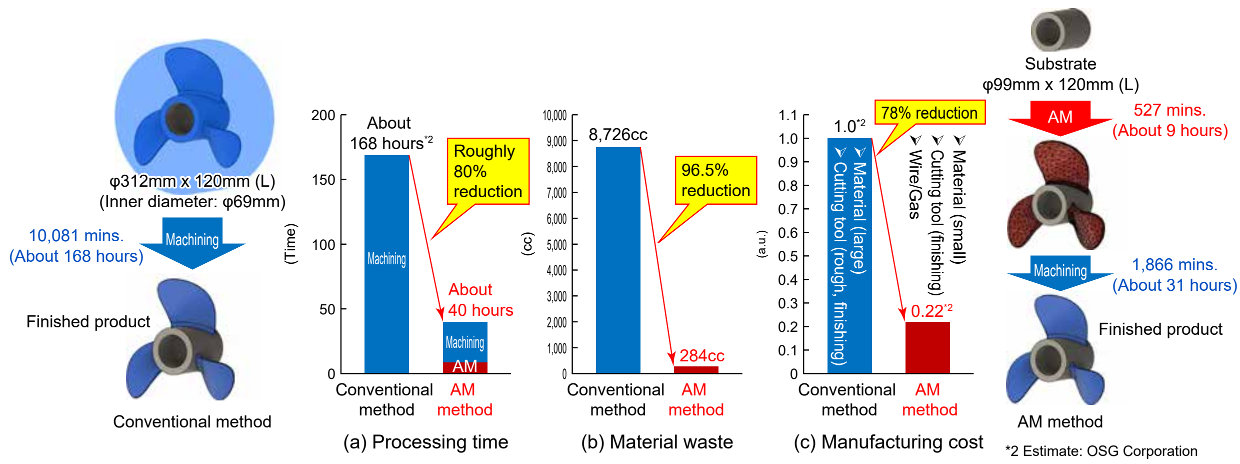


Fig. 5 Comparison of conventional and AM method

3.2 Multi-material

Figure 6 shows an example of use for a drill used in the petroleum or natural gas industry, etc. These drills are used to cut through high-hardness materials such as sediments, in harsh environments where high-temperature seawater and highly-corrosive gases spurt out. The possibility was considered of fabrication via the conventional method of cutting a hard-to-machine, wear/corrosion-resistant material, but that was unrealistic because it is time-consuming and costly. Therefore, a key issue is the trade-off between cost and service life.

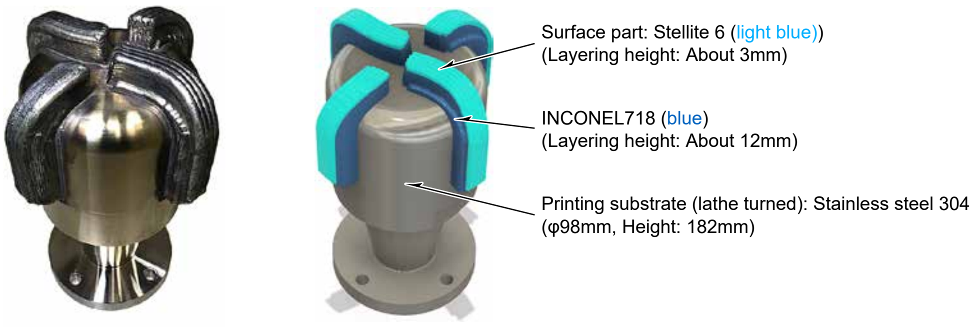


Fig. 6 AM method using heterogeneous materials

In this example, each blade body was first produced through additive manufacturing using wire made from INCONEL*3 718, a nickel-based alloy which has outstanding corrosion resistance to many media under high temperatures. Then each blade surface was coated, via additive manufacturing, using wire made from Stellite*4 6, a cobalt-based alloy with outstanding wear resistance. Printing time is about 2.5 hours in total. Stainless steel 304 was used as the substrate in consideration of material cost, machinability, and corrosion resistance.

Higher part functionality and lower manufacturing cost can also be achieved by adopting a multi-material approach, where necessary materials are used at the necessary points.

*3 INCONEL is a registered trademark of Huntington Alloys Corp.
*4 Stellite is a registered trademark of Kennametal Inc.

3.3 Overlay repair and welding

Figure 7(a) shows an application example assuming the repair of die-casting molds. 10mm × 45° corner chamfer simulated defects were produced at the corners of a workpiece made of H13 tool steel hot work tool steel, and overlay repair was carried out through additive manufacturing using maraging steel wire. Printing time was 4 minutes per corner. After that, part of the printed section was cut and polished. No flaws like cracks or voids were evident in the repaired part, and it was confirmed that the original workpiece form could be restored.

Figure 7 (b) is an example of applying groove welding. The groove angle and depth were so large as 30° and 15mm, making it one of the most difficult types of groove welding. In this example, the groove part of a 200mm long stainless steel 304 workpiece was welded with a multi-layer stack of 17 layers using stainless steel 308L wire, and the processing time was approximately 10 minutes.

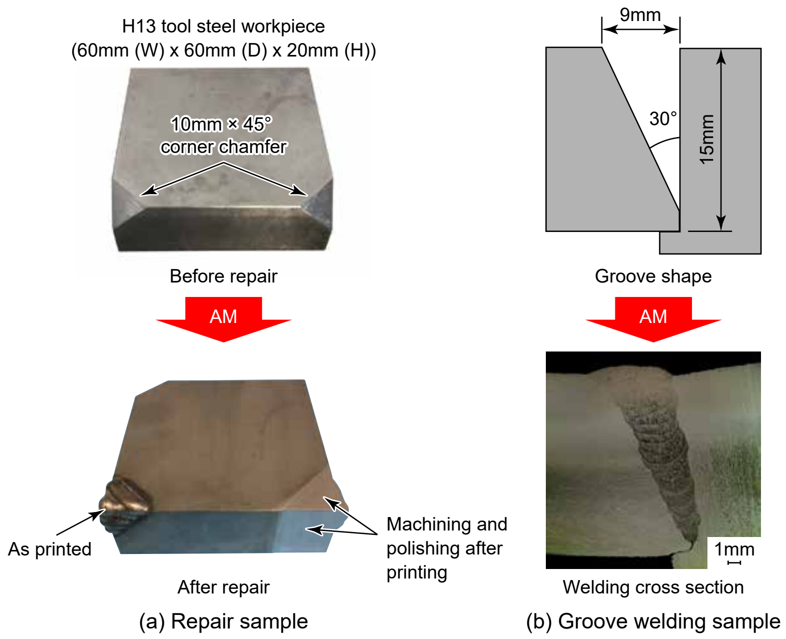


Fig. 7 Overlay repair and welding

The work in both cases required experience and know-how and was therefore individualized, leading to problems such as labor shortages and unstable quality. By performing these works using the AZ600, it is possible to not only stabilize quality but also meet needs for automation and labor savings.

4. Conclusion

We have described the features and effects of using our company's wire-laser metal 3D printer AZ600. This technology can shorten manufacturing time, and reduce material waste and tool depletion. It can therefore be expected to contribute to carbon neutrality.

The features of AM technology will have to be correctly understood for AM technology to come into wider use. We at Mitsubishi Electric will expand applications of the AM method by utilizing the AZ600, based on mutual understanding of AM technology with our customers. We will also continue development, by enhancing functionality of the system to meet market needs, so we can offer customers greater use value.

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