# Manufacturing Technology of LAMDA Three-Dimensional Metal-based Additive Manufacturing System Using Powder DED Method


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*Powder DED (Directed Energy Deposition) metal-based additive manufacturing is characterized by its fast manufacturing speed and ease of increasing the equipment size. On the other hand, it also has issues such as metal deterioration caused by oxidation occurring in the process of melting and solidification during manufacturing, as well as securing the shape and dimensions. Mitsubishi Heavy Industries Machine Tool Co., Ltd. uses its own LAMDA powder DED three-dimensional metal-based additive manufacturing machine equipped with a local shield to manufacture sample aircraft parts while suppressing the oxidation of titanium alloy, which is an active metal. This machine is also able to suppress shape collapse during manufacturing by optimally controlling the heat input using the monitoring function system.*

## 1. Introduction

By using metal-based additive manufacturing, it is possible to reduce the part weight and integrate parts due to the realization of shapes that could not be manufactured by conventional removal processing, improve design, enhance the functionality using multi-layer manufacturing of dissimilar metals and reduce parts inventory. For this reason, metal-based additive manufacturing is attracting attention as a next-generation technology that can contribute to improvement in product performance and supply chain innovation. The LAMDA powder DED three-dimensional metal-based additive manufacturing system (hereinafter referred to as LAMDA), which we developed, is characterized by its fast manufacturing speed resulting from the additive manufacturing principle and the ease of increasing the equipment size. On the other hand, it has issues such as securing the mechanical properties, shape and dimensions of the manufactured metal, as well as stability over lengthy manufacturing processes. This paper describes an overview of LAMDA, our approach to the issues it faces and presents manufacturing case examples.

## 2. Additive manufacturing principle and features of DED method

Powder DED, which is also known as the directed energy deposition method, is a technique that uses a laser as a heat source to melt and solidify locally-fed metal powder together with a substrate to manufacture a three-dimensional shape by overlay welding (**Figure 1**). Due to the additive manufacturing principle, powder DED has the following features:

(1) The manufacturing speed is about 10 times faster than that of the powder bed method.
(2) Metal powder is directly fed to the manufacturing position, so increasing the equipment size is easy.
(3) Manufacturing on an existing part is possible, so adding shapes, repairing and coating processes can be carried out.
(4) Multi-layer manufacturing of dissimilar metals is possible by switching the material during manufacturing.

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Because of the features above , the technology is expected to be used to manufacture high-functionality parts and repair used parts in the fields of aerospace, energy and automotive, as well as to innovate parts production processes. On the other hand, the use of active metals such as titanium—a type of high-performance material increasingly used in aircraft parts—has the problem of metal deterioration occurring due to oxidation during the process of melting and solidification in manufacturing. In addition, manufacturing a large part with high accuracy and stability requires control of the heat input according to the shape of the part, and a mechanism to stop the equipment safely, when an abnormality in the manufacturing process is detected, is also necessary.

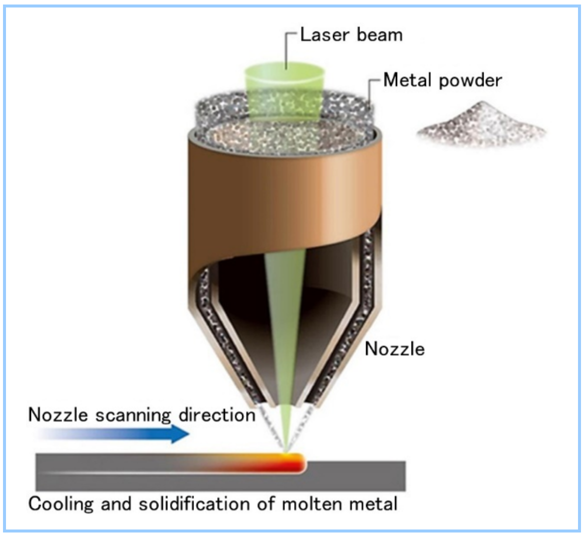


**Figure 1 Powder DED metal-based additive manufacturing method**

## 3. Overview of LAMDA

We market the series of LAMDA models according to the manufacturing size (**Figure 2**). The LAMDA 200 is targeted for small-size manufacturing and is suitable for manufacturing small parts, developing manufacturing methods, accumulating manufacturing expertise and evaluating prototypes. The LAMDA 500 and LAMDA 2000 are capable of manufacturing larger parts, and the maximum manufacturing size of the LAMDA 2000 is 2000 mm x 1500 mm x 1600 mm.


| | LAMDA 200 | LAMDA 500 | LAMDA 2000 | |
|---|---|---|---|---|
| Maximum manufacturing size [mm] | 200 × 200 × 200 | 500 × 500 × 500 | 2000 × 1500 × 1600 | 2500 × 900 × 1000 |
| Laser power [kW] | 1, 2, 4, 6 | | | |
| Number of powder feeding pots | 1 (up to 2 available as option) | | | |
| Inert gas shield | Available | | | |
| Spindle | Available as option | | | N/A |
| NC axis table | 1-axis or 2-axis table available as option | | | |
| Tool cooling | Available as option | | | |
| Machine size (foot print) [mm] | 4000 × 2600 | 4100 × 5000 | 12000 × 6500 | 7000 × 5500 |
| Machine weight [kg] | 2500 | 7500 | 44000 | 12000 |
| Metal material | Titanium alloy, Inconel, Stainless, *Maraging steel, *Cobalt chrome alloy, Invar (*Under Developing) | | | |

**Figure 2 LAMDA series**

This paragraph and the next describe the LAMDA main unit and peripherals. The machine main unit has an XY-axis driven table and a Z-axis driven additive manufacturing head. When a 2-axis rotary table is added, 5-axis additive manufacturing is possible. The additive manufacturing head has a built-in optical system, which focuses laser beam on the substrate. It is possible to observe the molten pool by installing a sensor such as a camera coaxially with the laser beam. The head is equipped with a powder feeding nozzle on its tip, which feeds metal powder accurately to the laser focusing position on the substrate. When a cutting spindle is also mounted, it is possible to perform preparatory processing before repair manufacturing or finish processing after manufacturing.

The peripherals include a laser oscillator, a chiller and a powder feeder, as well as a dust collector for powder recovery. Up to two pots can be installed for the powder feeder, and the material being fed can be switched during manufacturing.

## 4. Features of LAMDA

For LAMDA, powder feeding nozzles for handling various manufacturing processes according to the purpose are offered, as is a monitoring function for stable manufacturing over lengthy manufacturing processes.

### 4.1 Powder feeding nozzle and local shield

High-precision additive manufacturing means manufacturing a metal with the required mechanical properties with high shape accuracy. For LAMDA, two types of nozzles—a 3-port feeding type and an all-around feeding type—are available so that the nozzle can be selected according to the shape of the part, required accuracy and manufacturing speed. **Figure 3** shows the powder convergence state of the two nozzles. The metal powder converges at the nozzle standoff setting position during manufacturing, and the convergence diameter is approximately the focusing spot diameter of the additive manufacturing head optical system. Accurately converging the metal powder makes it possible to perform manufacturing with the target shape and dimensions. In addition, a local shield can be added to prevent active metals from oxidizing during manufacturing. **Figure 4** presents the local shield and the result of fluid analysis during shielding. By injecting an inert gas from the outer circumference of the nozzle, a shield is created locally at the melting/solidifying position, which prevents the inflow of air and avoids oxidation.

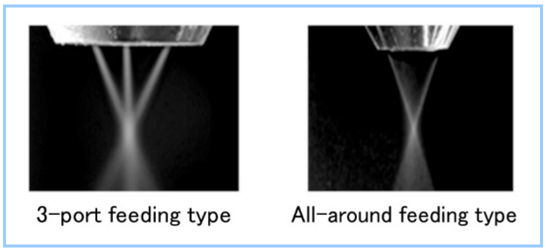


**Figure 3 Powder feeding nozzle**


**Figure 4 Local shield and result of fluid analysis**

### 4.2 Monitoring function

The powder DED method performs manufacturing while melting the substrate with a laser beam. However, since the melting degree of a metal changes depending on the material type and shape of the substrate and the degree of overheating and cooling during manufacturing, it is desirable to change the laser power according to these conditions. If a metal-based additive manufacturing machine has a function of optimally controlling the laser power according to the additive manufacturing conditions, stable lengthy manufacturing processes are possible. To achieve this, LAMDA has a monitoring feedback function. In addition, since sputter, fumes, etc., during manufacturing may damage the equipment, we are developing an AI-based abnormality detection function.

(1) System configuration

**Figure 5** is a system configuration diagram of the monitoring feedback function. A camera installed coaxially with the laser beam enables observation from directly above the melt pool during manufacturing. This is based on the idea that a change in the state of the substrate appears as a change in the melt pool. The melt pool image is analyzed by a dedicated PC in real time during manufacturing, so it is possible to immediately detect changes during manufacturing. Based on the detected amount of change, the manufacturing position and laser output command can be feedback-controlled. By detecting abnormalities such as sputter at the same time, the equipment can be safely stopped in order to prevent damage.

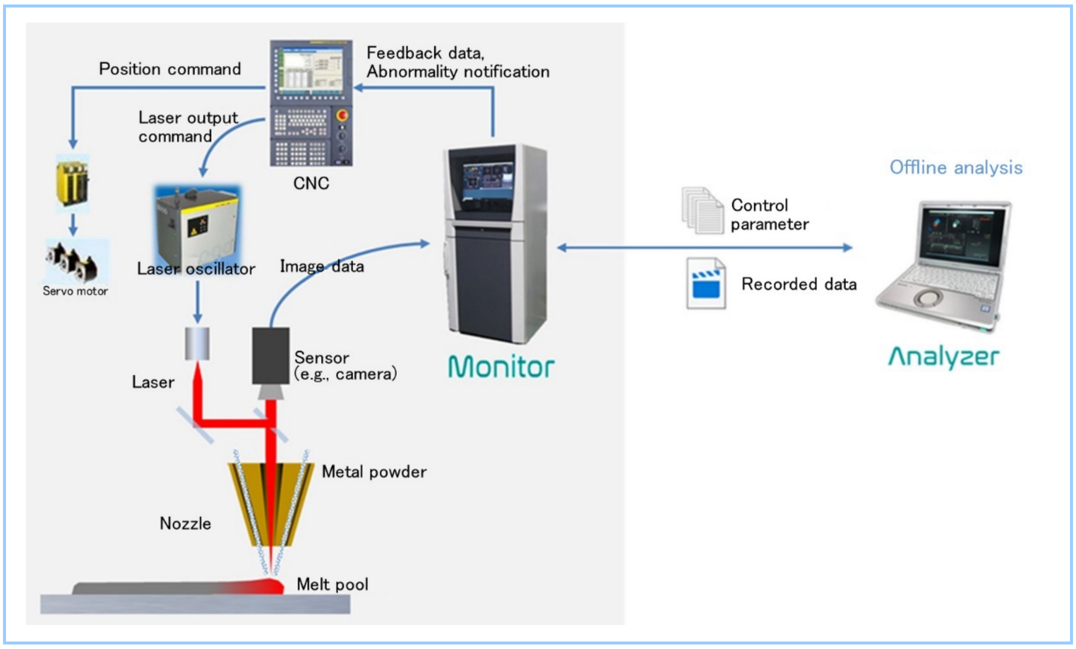


**Figure 5 Monitoring function system configuration**

(2) Effect of feedback

**Figure 6** shows the results of manufacturing with the feedback function turned ON and OFF. When the feedback function was turned OFF, as the additive manufacturing height increased, the balance between heat input from the laser beam and cooling collapsed and heat input became excessive. This increased the melt pool size, and the shape collapsed as a result. When the feedback function was turned ON, the laser output was controlled to stabilize the melt pool size during manufacturing. As a result, manufacturing could finish without causing shape collapse.

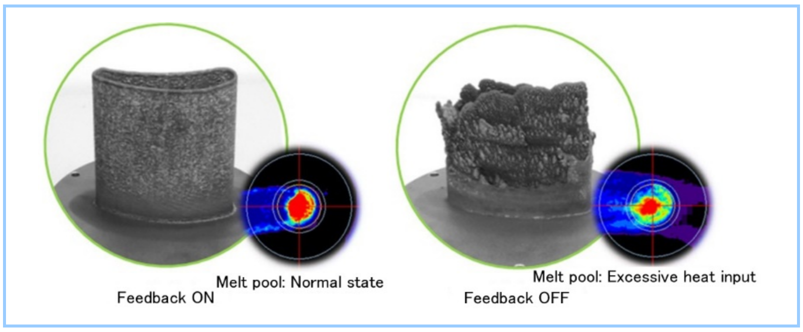


**Figure 6 Effect of monitoring feedback**

(3) Abnormality detection during manufacturing process

When an abnormality occurs, the melt pool image shows some changes from the normal state. By capturing these changes, the abnormality can be detected. Typical types of abnormalities are as follows.

1. Sputter

    Sputter may be produced when the manufacturing conditions are unstable. Sputter affects the manufactured metal quality.

2. Dirt on protective glass

    Dirt may adhere to the protective glass in the manufacturing nozzle due to sputter caused by poor manufacturing conditions or fumes generated from the melt pool. The dirt on the protective glass lowers the laser transmittance and may cause defective manufacturing or damage to the nozzle.

3. Foreign matter adhered to nozzle

    If sputter, etc., produced during manufacturing adheres to the nozzle, the adhesion area may generate heat and damage the nozzle.

Abnormality detection is not a matter of simply checking whether a threshold has been exceeded, but rather requires complex criteria that are close to human perception. Therefore, we incorporated AI in the monitoring system to detect abnormalities. The left side of **Figure 7** gives examples of abnormalities occurring during manufacturing, and the right side shows images of the abnormalities at the time of occurrence. It can be seen that there is a difference between the images of the normal and abnormal states. The prompt detection of anomalies during manufacturing not only prevents manufacturing defects, but also protects the manufacturing head from damage. This reduces downtime as a result.

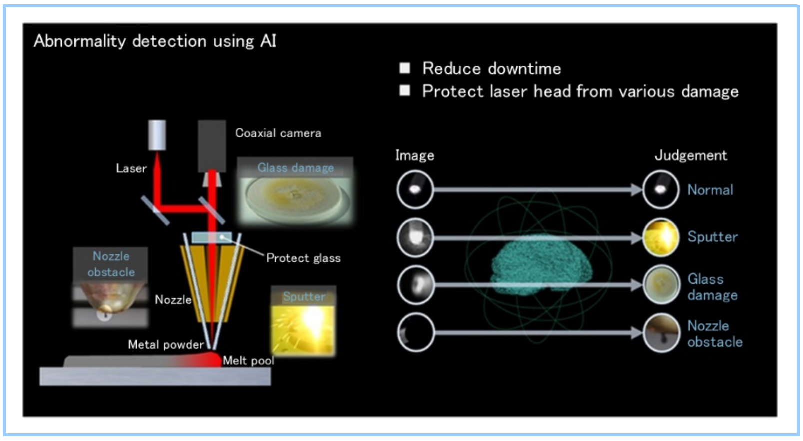


**Figure 7　Abnormality detection during manufacturing**

## 5. Manufacturing case examples

This section introduces manufacturing case examples of LAMDA.

### 5.1 Titanium alloy aircraft part

A titanium alloy ($Ti_6Al_4V$) simulated shape with a tilted cylinder and ribs, that is assumed to be used as a general aircraft part, was manufactured under an atmospheric environment using a local shield nozzle. **Figure 8** shows the manufactured result. This part was manufactured using a LAMDA 500 prototype machine with a cutting spindle. By adding a cutting process in the middle of the manufacturing process, a highly-accurate finish was obtained. By using near net shape manufacturing of titanium alloy parts, it is expected that the product lead time will be shortened and the processing cost will be reduced.

### 5.2 Low thermal expansion alloy bracket

**Figure 9** shows a manufactured sample made of super invar, which is a low thermal expansion alloy. Super invar has a very small coefficient of linear expansion, about 1/100 of that of iron, and is often used for parts in environments with severe temperature changes and precision parts. On the other hand, since it is a difficult-to-process material with low thermal conductivity, the advantages of near net shape manufacturing are significant. In general, high-performance materials often take a long time to procure. However, additive manufacturing of such a material can be performed as long as the metal powder is in stock, so the lead time can be significantly shortened.

### 5.3 Hollow gear

**Figure 10** is a hollow gear manufactured as a sample for display by manufacturing stainless steel SUS304 on a SS304 substrate. The use of metal-based additive manufacturing makes it possible to manufacture hollow parts that could not be made by conventional removal processing.

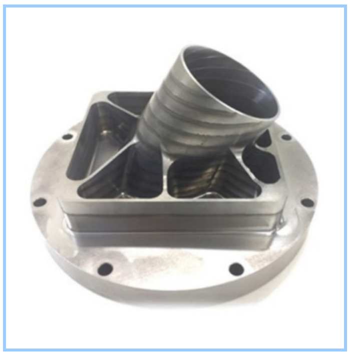

**Figure 8 Titanium alloy part**

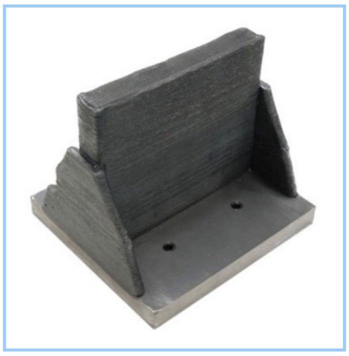

**Figure 9 Low thermal expansion alloy bracket**

**Figure 10 Hollow gear sample**

## 6. Conclusion

This report introduced the principle and features of powder DED metal-based additive manufacturing, and the powder feeding nozzle, local shield and monitoring function of LAMDA that realize the stable manufacturing of high precision parts. Moving forward, we will further improve these technologies, actively promote trial manufacture and evaluation to expand applications and work on the spread and practical application of metal-based additive manufacturing technologies.

This research and development effort uses the achievements of the Ministry of Economy, Trade and Industry commissioned project "Monozukuri Revolution Program using 3D shaping technologies as a core (Technological Development for Next-Generation Industrial 3D Printers and Ultra-High-Precision 3D Shaping Systems)," as well as from a project supported by the New Energy and Industrial Technology Development Organization (NEDO).

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