光加工機 Lasermeister 100A/101A の開発

上野和樹

Development of the Lasermeister 100A/101A optical processing machine

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ものづくりに新たな市場と産業を創出することを目的に，従来の「大きい」「高価」「操作が複雑」という金属3D プリンターのイメージを刷新する光加工機「Lasermeister 100A」を2019年４月，さらに「５軸化による造形制約の開放」「対応材料の拡充」に対応した「Lasermeister 101A」を2020年５月にリリースした．本稿では光加工機の基礎となる様々な開発要素について説明する．

In April 2019, Nikon released the optical processing machine Lasermeister 100A that renews the image of the conventional large, expensive, and complex-operation metal 3D printer with an aim of creating a new market and industry for manufacturing. Thereafter, the optical processing machine Lasermeister 101A was released in May 2020, which has features such as opening of molding restrictions by 5 axes and the expansion of compatible materials. This paper describes various developmental factors that form the basis of optical processing machines.

Key words 光加工機，金属3D プリンター，積層造形，レーザーメタルデポジション
optical processing machine, metal 3D printer, additive manufacturing, laser metal deposition

1 Introduction

In April 2019, Nikon released its first optical processing machine Lasermeister 100A, followed by its successor model Lasermeister 101A in May 2020. This paper describes various developmental factors that form the basis of optical processing machines.

2 Laser Metal Deposition

Nikon's first optical processing machine was created to open a new market and industry for manufacturing. The optical processing machine not only functions as a 3D printer capable of metal additive manufacturing, but also as a composite machine that uses light to perform operations such as improving the surface roughness of the modeled object by laser re-melting, and marking on a metal surface. Particularly, in the main feature, which is metal additive manufacturing, laser metal deposition (LMD) method is adopted instead of the generally used powder bed fusion (PBF) approach.

The PBF and LMD methods are explained in Fig. 1. In the PBF method, a metal powder material is preliminarily laid on a flat surface and sintered by scanning with laser; this process is repeated for each layer to form the modeled object. While it has the advantage of having a relatively good molding accuracy, the disadvantages include the limitation of being modeled only on certain standard base materials, and the large amount of metal powder used, while the molded object gets buried in the metal powder. Conversely, in the LMD method, first, a melt pool is formed by laser irradiation, followed by melting and solidifying while spraying the metal powder, which is repeated for each layer to form the molded object. The advantages include the possibility of additional processing regardless of the form of the base material, and the less amount of metal powder used, while the modeled object can be observed and confirmed from the outside, as it does not get buried in the metal powder. However, modeling accuracy is a problem.

“Lasermeister 100A/101A” employs the LMD method, which is considered to be reasonable with high future potential, and incorporates various development factors to improve modeling accuracy.

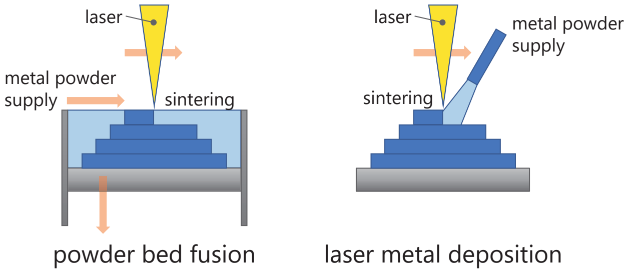

Fig. 1 Illustration of PBF (left) and LMD (right) methods

3 Usable Metal Power Materials and Safety

Lasermeister 100A can use the stainless-steel metal powder SUS316L to lower Mn, which is performed in consideration of the Ordinance on Prevention of Hazards Due to Specified Chemical Substances. Because the dust explosiveness evaluation revealed that it does not come under dangerous materials in the small gas flame ignition, the hurdle in its introduction is less. The equipment has also been evaluated for safety by a third-party certifying body, according to the European standards. By filling the process chamber with nitrogen gas during laser processing, we ease its use in consideration of high safety against an accidental dust explosion. Although invisible infrared laser is used as the processing light, the window provided on the front door has multiple light-shielding measures, and the laser product as a device has achieved Class I, regardless of the interior being visible. Therefore, from the viewpoint of laser equipment, it can be used safely. Furthermore, by developing a special recipe for Lasermeister 101A, it is made compatible with high-speed steel and nickel-based metals.

4 Miniaturization and Semiconductor Laser

The device dimension is W: 850 mm × D: 750 mm × H: 1700 mm, which is much more compact than conventional metal 3D printers, and thus, space saving is realized (Fig. 2). Because the laser and all other equipment are packaged in one housing, when power supply, together with exhaust and nitrogen gases, is provided, it can be operated on a stand-alone basis. The weight of the equipment excluding metal powder is 320 kg. The processing range of Lasermeister 100A is W: 297 mm × D: 210 mm (A4 size) × H: 200 mm, while that of the five-axes version, Lasermeister 101A, is ϕ150 mm × H: 150 mm.

As a point of miniaturization, the use of semiconductor lasers can be mentioned. Usually, a semiconductor laser used as a special light, such as a fiber laser, is directly used for processing through an optical lens barrel designed by Nikon. The maximum output is 200 W, and by using air cooling, the units surrounding the coolant are eliminated, which has greatly contributed to downsizing. Moreover, by utilizing the semiconductor exposure equipment development technology, the internal units are modularized by appropriate partitions to achieve both exterior design and functionality. An interface called the operator console is provided on the front of the device, and using the touch panel, operation and confirmation of device status by various sensors become possible.

Since a lightweight and compact device has been realized, it can be loaded into a normal elevator when bringing in, and be started up immediately after connecting the wiring and piping. Hence, it is highly mobilizable, as it can be installed anywhere.

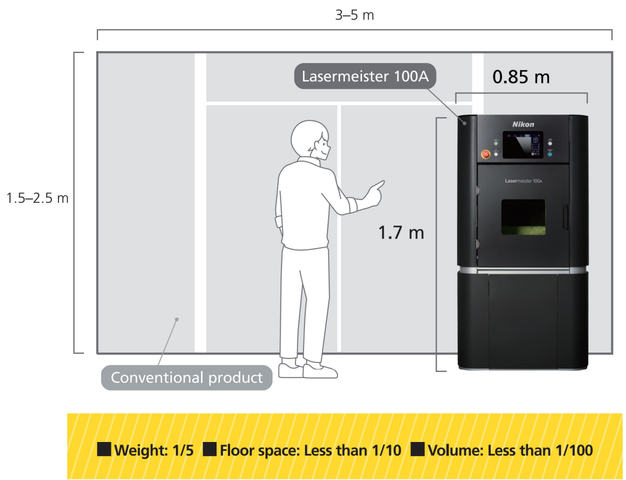

Fig. 2 Light and compact design.

5 Setup-less due to 3D Alignment

The greatest feature of Lasermeister 100A/101A is its 3D alignment function, which automatically positions the workpiece using a 3D scanner uniquely designed by Nikon and placed inside. Since there is no need for complicated positioning work after placing the base material to be processed, a setup-less process is achieved.

The process is explained step by step in Fig. 3. First, the machining base material and the 3D model of the product are prepared. Next, the machining base material is placed at an arbitrary position on the machining table. Conventionally, as a setup, the position of the machining base material placed on the machining table is measured with a stylus or the like, after fixing it with a jig. Conversely, in 3D alignment, the coordinates of the machining base material are estimated by measuring the unique points using the built-in 3D scanner and matching them against the 3D model of the machining base. Based on it, by placing the 3D model of the machining base material at the recognized position on the machining table in the virtual space, the actual arrangement is reproduced on the computer. Furthermore, by placing the modeled 3D model at an arbitrary position on the 3D model of the machining base material, it is possible to easily perform additional processing at any desired position.

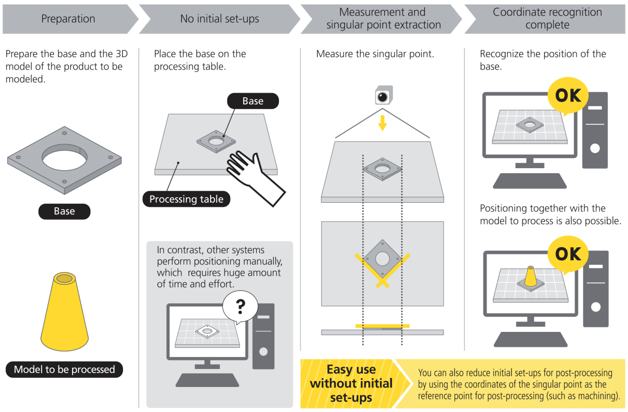

Fig. 3　3D alignment

Among the various methods, such as those of the optical cutting and time-of-flight, the 3D scanner employs the stereoscopic phase shift method. In this method, multiple stripe patterns are projected on to the measurement target through a projector, which is the light source, while the target shape is measured by a two-lens camera (Fig. 4). Since the base material, which is the measured object, is a metal, it is difficult to capture the reflected light, and there exist aspects where the measurement is challenging. However, the reason for choosing this method is that, in the evaluation of methods by comparison, measurement of a metal was relatively easy, and it was suitable in terms of the device size and measuring distance.

The basic process is straightforward with a simple graphical user interface via a touch panel, and the measurement, including the processing of measured data, can be completed in a short time. In addition, it has a function that teaches the manually machining the starting points more easily by using the two guide lights provided on the lens barrel, without using the 3D alignment, together with functions to teach multiple points and specify a virtual plane.

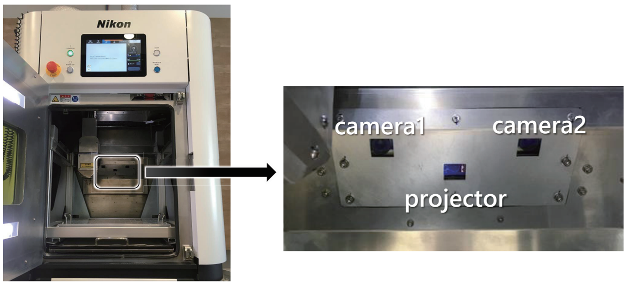

Fig. 4　Built-in stereoscopic phase shift 3D scanner

6 Changing to Five-axes and Relaxation of Modeling Restrictions

The details of the drive unit are described below. “Lasermeister 100A” is equipped with a gantry type XYZ orthogonal three-axes stage, and has a structure called processing head that drives the lens barrel and the powder supply nozzle. Lasermeister 101A is equipped with a tilt rotation stage that has two axes, with θx rotating around the X-axis, and θz around the Z-axis, and a five-axes configuration that drives the base material side. In each device, the machining path corresponds to the G code used in the NC program. Since Lasermeister 100A has a three-axes configuration, G code can be created manually. However, with the dedicated software installed in the device, it can be automatically generated using STL data, which is in 3D CAD file format. Using the function called slicer, a machining path can be generated for each layer at a fixed pitch in the height direction of the model. The optimized parameters for the driving speed of the processing head, the output of the laser, the rate of supply of the metal powder at that time, are automatically selected according to the material. Since, by providing the STL data, the user can perform modeling immediately without having to evaluate complex modeling recipes, and thus, a great convenience is realized. In addition, when performing additional processing on an existing part, it is possible to consider an arrangement in which the 3D model of the workpiece overlaps that of the machining base material. However, since the model difference extraction function is available, it can be easily used to repair missing parts. In the usual PBF-type metal 3D printer, when modeling an overhang shape as shown in Fig. 5, it is necessary to simultaneously model multiple pillar structures called the support material. This is to prevent sagging when melted by laser irradiation, as there is no base in the overhang portion. The support material is set by the user when generating the machining path for modeling. In addition to affecting the accuracy, the cutting and removing after modeling to make the final product takes huge effort.

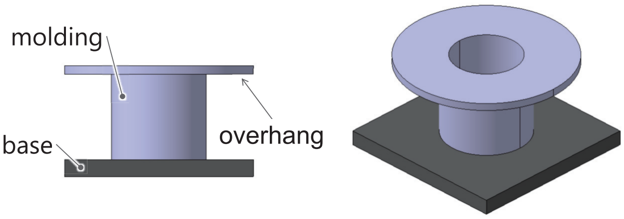

Fig. 5 Example of modeling an overhang shape

On the other hand, if LMD method and five axes are used, modeling without support is possible by performing tilting and rotation at the overhang part, as shown in Fig. 6. Although it is partially possible to model an overhang part protruding at an angle even with the three-axes type, since large angles cannot be obtained, the merit of using the five-axes type becomes large. In the case of five-axes machining, it is difficult to manually create the machining path. Hence, Lasermeister 100A/101A is compatible with some of the machining paths of five-axes machining CAM software.

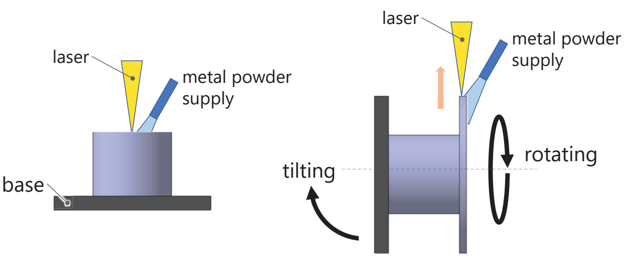

Fig. 6 Example of modeling an overhang shape by LMD five-axes modeling method.

7 Metal Powder Feeder

Although the LMD method has problems in terms of accuracy in general, one breakthrough is the stabilization of the rate of supply of metal powder.

This is only due to the material volume put into the melt pool. Forming the modeling bead with a stable volume leads to accuracy improvement of the final modeled object. In particular, the metal powder feeder is uniquely designed, and as shown in Fig. 7, it realizes metal powder feeding without a pulsation of even 5 mg in the short term.

A comparative image of the modeling bead that uses a powder feeder actually available in the market, and the modeling bead that uses the uniquely designed powder feeder, are shown in Fig. 8. This is a modeling bead formed by modeling multiple first layers in a line. It can be observed that the modeling bead eliminates fine cracks and difference in levels, and the stabilization of the rate of metal powder supply is directly linked to the modeling quality.

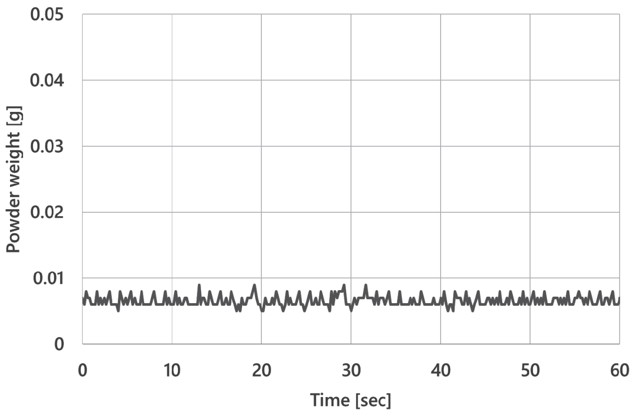

Fig. 7 Stabilization of the rate of metal powder supply by the original method.

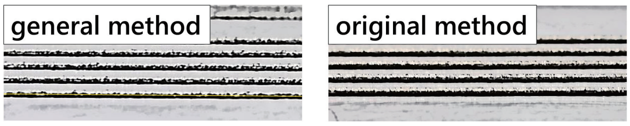

Fig. 8 Comparison of modeling beads

8 Feed-forward Control by Simulation

The shape of the modeling object has a great influence on the pursuit of modeling accuracy. Normally, it is difficult to automatically change the conditions for generating the machining path for the slicer according to the modeling shape. In Lasermeister 100A/101A, the parameters are automatically selected by a dedicated software, which can be converted into machining paths, while further optimization is also possible through a uniquely developed simulation. The mechanism is such that the optimal modeling parameters are calculated beforehand based on the simulation results, and the machining paths are adjusted directly.

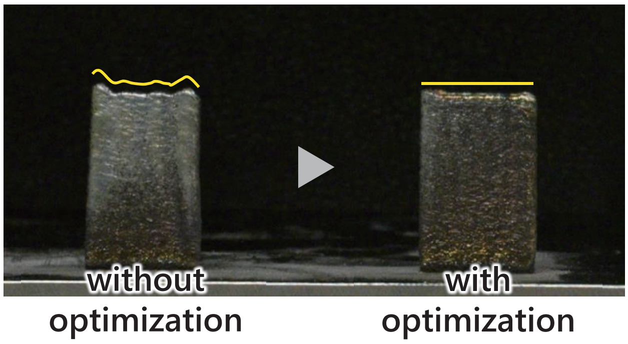

Fig. 9 Optimization of machining conditions and modeling accuracy.

Using this function to operate the device like a feed-forward control that reflects the modeling shape, the problem of modeling accuracy in the LMD method is resolved (Fig. 9).

9 Examples of Mechanical Characteristics of Modeled Objects

The mechanical characteristics of the modeled object become crucial when considering the final product. The mechanical characteristics of an in-house standard test piece, which is modeled using SUS316L powder, with the material used in Lasermeister 100A/101A being standard, is explained as follows.

JIS standard stainless-steel bars are used for reference and comparison. First, the results of the tensile test of the model without any processing, such as heat treatment, are given in Table 1. The sample size is set to five. It can be seen that the maximum stress, which is the 0.2% proof stress, and the elongation, meet the standard values for stainless-steel bars. Although there is no standard value, the Young's modulus is measured by the resonance method, as shown in Table 2. It can be seen that the numerical value is higher than that of the test piece modeled by the PBF method, and is almost comparable to that of the rolled material.

Table 1 Tensile Test Results

Test piece No.	Maximum stress [MPa]	0.2% proof stress [MPa]	Elongation [%]
1	498	309	52.2
2	494	327	51.5
3	495	330	48.7
4	496	328	49.9
5	495	328	49.8
Standard value	480 or more	(175 or more)	40 or above

Table 2 Results of Young's Modulus Test by Resonance Method

Test piece	Temperature [°C]	Young's modulus [GPa]
Made by Nikon	25	184
Made by PBF method	25	168
Rolled material (rolling direction)	25	187
Rolled material (direction orthogonal to rolling)	25	194

Next, the results of the hardness test are presented in Table 3, in which the sample size is three, whereas the minimum, maximum and average values measured at multiple locations are also given. Without solution heat treatment, there are some points in the area near the base material, the starting point of modeling, where the hardness exceeds the standard value (HRBS90 or less). However, after the solution heat treatment, the standard values are satisfied at all measurement points.

Table 3 Hardness Test Results (Before and After Solution Heat Treatment)

HRBS	Before heat treatment			After heat treatment		
	No. 1	No. 2	No. 3	No. 1	No. 2	No. 3
Min	88.5	89.0	88.0	84.5	84.5	84.0
Max	94.5	93.5	94.5	88.0	88.0	88.0
Avg	91.8	91.6	91.7	86.2	85.9	85.6

Moreover, the inverse pole figure orientation map for crystal analysis by electron backscatter diffraction is demonstrated in Fig. 10.

For comparison, materials made by PBF and rolling methods were also analyzed. From the map, it can be seen that, while the crystal grains of the modeled object are as large as those of the rolled material, those of the PBF method are smaller. None of the crystals have orientation, and since the modeled object and the rolled material have less color unevenness, the intra-grain strain is considered to be small.

From the aforementioned results, it can be inferred that the mechanical characteristics of the modeled object are closer to the rolled materials than to the PBF method. This could be explained as follows: the LMD method forms a melt pool and sprays metal powder so that it completely melts and solidifies; unlike the PBF method where high-speed laser operation is used, here, because the processing head is physically driven, the rapid thermal change of the model is small.

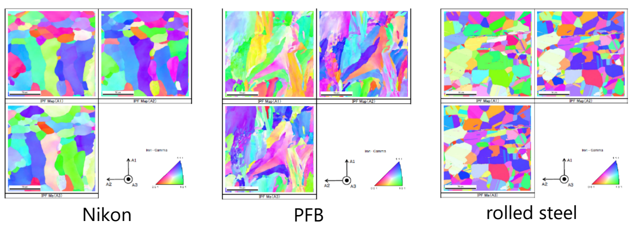

Fig. 10 Inverse pole figure orientation map.

10 Modeled Sample

A sample of modeling a heat exchanger with a lattice structure by Lasermeister 100A/101A is shown in Fig. 11. In such lattice structure, a coolant flow path that maintains the overhang angle without support material, is provided inside, while the surface area is increased by modeling the structure to greatly enhance the heat exchange efficiency. This is a shape difficult to be achieved through conventional machining.

A repaired and finished sample is shown in Fig 12, in which cracks simulating pipe damages were made and the overlay was repaired by modeling.

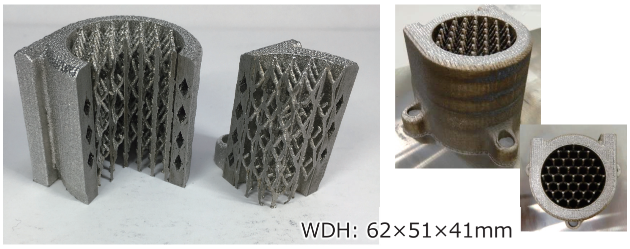

Fig. 11 Heat exchanger with a lattice structure.

The overlay welding restoration, which generally requires craftsmanship by skilled welders, can be easily performed by Lasermeister 100A/101A.

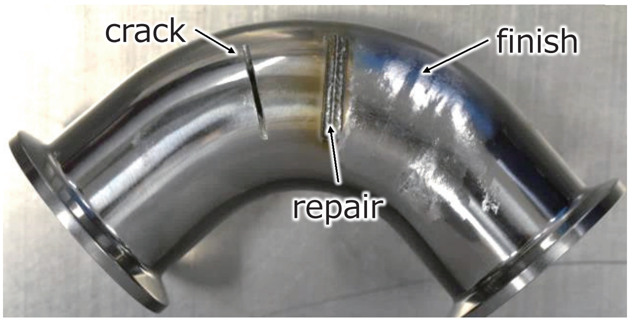

Fig. 12 Repair of damage in a pipe.

A sample is shown in Fig. 13, in which additional processing of a pipe of diameter 14 mm was performed on an existing flange using five-axes and then the surface was finished. Thus, bending points can be provided at any position within the modeling range, while designing and modeling at any angle is possible. Because this is a process of direct addition to the flange, unlike the PFB method, wire cutting of the model is not required, which is a great advantage. By contrast, in the conventional method, it is necessary to manually prepare a mold according to the bending process and angle, together with welding work.

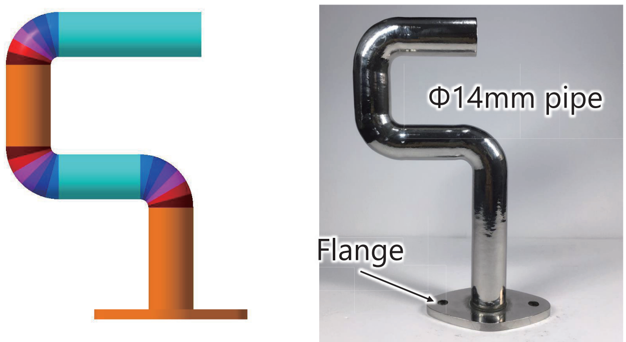

Fig. 13 Sample of pipe modeling with five-axes.

11 Summary

Lasermeister 100A/101A is a device developed to renew the conventional image of “large”, “expensive”, and “complex-operation” 3D metal printers with a goal to create a new market and industry for manufacturing. In addition to incorporating various uniquely developed items to improve modeling accuracy, which was a problem in the LMD method, we also offer easy operability to the user. Shapes that were difficult to process up to now, such as the samples introduced, can be realized with this device. In the future, we will continue to challenge new possibilities of material processing while adding and evolving functions that directly correspond to the pain points of users.

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