Design of Machines and Structures, Vol. 11, No. 1 (2021), pp. 39–45.
https://doi.org/10.32972/dms.2021.005

ADDITIVE METAL PRINTING MACHINE TOOLS

LOTÁR LÁSZLÓ KISS[1] – GYÖRGY TAKÁCS[2]

[1, 2]*University of Miskolc, Department of Machine Tools*
3515 Miskolc-Egyetemváros
[2]*takacs.gyorgy@uni-miskolc.hu*
[2]*https://orcid.org/0000-0002-5578-9091*

Abstract: The 3D printing, as a modern manufacturing method, is becoming more widespread and overrides the usual industry conventions. While it was mainly known in the production of plastic parts, nowadays metal-based versions are also becoming more widespread. Reputable machine tool manufacturers such as DMG Mori or GE compete with each other to create equipment for this technology for the industry, where there is a growing market for such machines. My article seeks to answer the question of where these tools have a place in the industry, whether they can be considered as machine tools, and decide that the procedures describing the construction of machine tools could be applied to them.

Keywords: *metal printing, 3D printing, machine tool, definition, morphology, function block sketch*

1. INTRODUCTION

Metal printing processes, like the plastic versions, can be derived from RPT (rapid prototyping) processes, and these foundations can also be discovered on machines currently used in industry. Although the naming conventions differ from model-to-model, basically most implementations can be treated as a sub-version of DED (direct energy deposition) and PBF (powder bed fusion).

In the case of direct energy deposition, basically the workpiece can be expanded with additional geometries, even with an additional DED head mounted on a CNC cutting machine (hybrid machining). However, in the case of powder bed fusion the entire workpiece is made of metal powder by using a laser's energy to locally melt the powder. Since the latter can be considered as a separate process in itself and as an apparatus, the article is hereinafter limited to this.

2. PRACTICAL APPLICATIONS OF INDUSTRIAL METAL PRINTING

During the research of the metal printing processes, a question may arise that after all do we really need this technology at all. There are countless examples that are hard or impossible to implement with traditional technologies – e.g. the case of cooling ducts running inside the part, the case of parts where most of the material needs to be machined, or a combination of material qualities and complex geometries that are difficult to machine.

Figure 1. *3D printed Ti-Al alloy blades for Boeing power units* [5]

A specific example is shown in *Figure 1*, where Boeing forms Ti-Al alloy high-pressure turbine blades with internal cavities and cooling channels. Creating such a geometry from such a material by conventional methods is not profitable and extremely cumbersome.

Figure 2 shows another example that shows that metal printing offers new possibilities in the field of design as well. The two parts offer the same rigidity in terms of load capacity, and it could be seen that the lower version can be made from fractions of the materials used in the machined version.

Figure 2. *Possible design of a bracket with machining and 3D printing* [6]

The two versions require a completely different design approach, while the first design focus on the simplest possible geometries and then accessibility with machining tools, the second case the viewpoints are the most efficient space filling and connection between the functional surfaces. This provides an opportunity to follow the current trend of weight reduction like in the automotive industry, and make such a relief on the manufactured, which has not been possible so far with conventional methods.

3. THE METAL PRINTING EQUIPMENT AS A MACHINE TOOL

An important and currently controversial question in the industry is, whether or not these machines can be considered as machine tools. To resolve this issue, I use the definition of a machine tool [3].

"A machine tool in the broadest sense is a machine that transforms workpieces with the tools captured in the machine according to the information provided by man, without human effort. According to the material of the workpiece, metal, wood, plastic, etc. machine tools are distinguished."

The broader definition of the definition can be interpreted without any modification for PBF devices, if the statement is acceptable that the workpiece is the dust and the tool is the laser. By implication, these machines belong to the group of metalworking machine tools.

"In a narrower sense, machine tools for metalworking machines, one of which is machining without chips (presses, hammers, rolling-, bending machines, etc.), the other one is cutting machine tools (lathes, drilling-, milling-, planing-, grinding-, gear-processing machines, etc.). …

The most important machines in the industry are machine tools because those are only tools that can reproduce themselves, and other machines can be made with them."

Although there is no specific category for these additive machines in the narrower definition yet, they can be classified as non-chipping machines or should be considered later that change the word "*cutting*" to *"removing or adding material"* in the future.

Since the key phrase of the definition is that such a machine should be able to reproduce itself, which is maximally fulfilled for these machines, I will consider PBF metal printing machines as machine tools in the rest of the article.

4. CONSTRUCTION CONSTRAINTS AND FEATURES

Before starting the analysis, it is generally worth looking at the constraints and features of PBF metal printing machine tools, which will be aided by *Figure 3* (https://en.dmgmori.com/products/machines/additive-manufacturing/powder-bed/lasertec-30-slm).

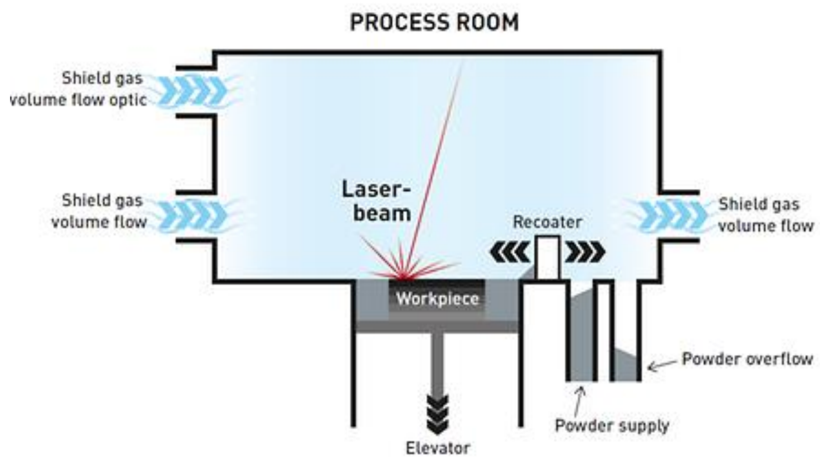

Figure 3. *Additive manufacturing by selective laser melting (SLM) in powder bed*

After spreading the powder layer, the entire cross-section of the workpiece is created with a laser beam, and then the process is repeated after the table has sunk. Examining the operation of the procedure, the following constraints can be identified:

1. The easiest way to spread the dust is done by gravity, the table must be placed in a horizontal position at the bottom.
2. The laser must be located on the opposite side of the powder bed so that it will work from above.
3. The laser should be able to cover the entire work area while it should not fall under a critical angle (~45°), because in this case it will more likely melt sideways rather than downwards.
4. The shielding gas supply should be laminar to not stir up the dust from the bed.

This is a surprising amount of constraint compared to a CNC cutting machine, but it will be seen later that there will still be a lot of options in the moving of the laser. Before examining the features, it is worthwhile to find out the definition of the D-number based on the source [3], to find out, how it can be interpreted in such a case.

“D-number for machine tools with serial kinematics:

The number of components in the forming mechanism that are capable of performing some elemental transformation (displacement or rotation) independently and simultaneously to create relative motion between the tool and the workpiece.”

According to this definition, since only stand-alone and simultaneous motion implementations have to be considered, PBF machine tools are 2D (or can be called 2.5D according to industry conventions), since moving the table is not simultaneous with moving the laser, and it only plays a positioning, stepping role. It also could be seen that the movement of the table, cannot replaced by the up and down movement of the laser, as it is necessary for dust spreading by the recoater.

Previously, in reinterpreting the definition of a machine tool, an analogy was established that the laser is the tool and the dust is the workpiece. It follows from this statement that the vertical axis is perpendicular to the powder table, pointing outwards from the laser, will be the Z + axis of the machine tool, and the other axes will be chosen to form a right-handed coordinate system accordingly.

5. Possible machine tool structures based on motion sharing and order

Although the constraints do not specify the construction kind of the kinematic chain of the machine, but serial kinematic solutions will be taken into account below as they have better workspace coverage. The machine tool structures that can be implemented on the basis of motion sharing and order, considering the constraints and features, are shown in *Table 1*.

Table 1

Possible second-order machine tool structures

	First-order solutions	**Second-order solutions**
1.	X(m), Y(m)	X(m,1), Y(m,2)
2.		X(m,2), Y(m,1)
3.	X(m), Y(s)	X(m,1), Y(s,1)
4.	X(s), Y(m)	X(s,1), Y(m,1)
5.	X(s), Y(s)	X(s,1), Y(s,2)
6.		X(s,2), Y(s,1)

Analyzing the variations, there are two options – moving the powder table or the laser sideways. In the first case, it should be kept in mind that the powder table can weigh tons if it is completely filled with powder, which is therefore difficult to move precisely.

In the case of moving the laser, mirrors can be considered, as well as moving the laser itself – in the first case, the protection of optical devices becomes a challenge, while in the second case, in addition to protection, there is also a risk of breaking power cables.

Considering the precision requirements for these machines and the serious movement challenge that the dust table would pose, it is much easier to move the laser beam with adequate protection it identifiable that PBF machine tools are recommended to be designed so that it is superimposed to the tool.

6. Comparative study of the main components of the PBF printer

Like cutting machine tools, PBF machine tools used in industry are made up of commercial or custom-made components. In many cases the components, in terms of their function and location, are comparable to the units used in cutting machines. The components to be compared are shown in *Table 2*.

Table 2

Machine tool components to be compared

Cutting machine tools	PBF machine tools
Spindle-motor	Laser
Cooling and lubrication system	Shielding gas system
Chip management system	Dust management system
Covers	
Slide rail systems	
Workpiece-switching system	Dust-removal system
Stands, holders	
Tool-switching system	–
	Recoater

For the study, the so-called function block diagrams have been prepared (their format is included in the source [3]), which show in a clear graphic format what functions the components have to implement and provide comparability between different solutions.

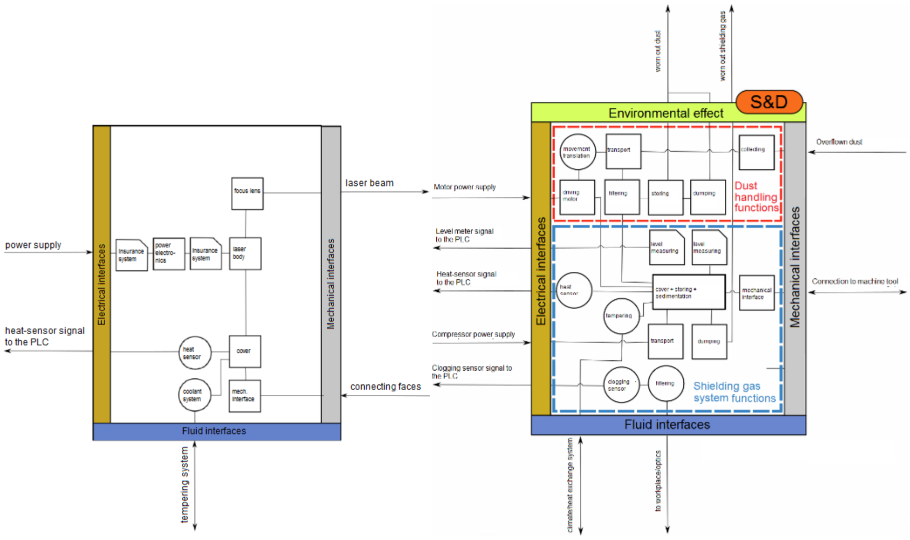

Figure 4. *Function block diagram of laser (left) and shielding gas/dust treatment (right)* [5]

As an example, *Figure 4* shows a schematic of the function block of the laser and shielding gas and dust treatment subsystem. Based on the figures of the cutting machines using the source [3], it can be seen that there are serious differences in the laser-spindle motor relation, while in the other case there are also serious similarities.

7. Specific implementations of some manufacturers

Reviewing the current industrial implementations available on the market, it can be stated that the previous findings of the article are applicable when examining them as well. Concepts such as workspace, machining accuracy can also be defined for these machines, and the components and features described earlier can also be found.

By summarizing the machines into a voluminous knowledge matrix [4], it is possible to determine the average parameters of the machine tools currently on the market. These can be used later for further design tasks. Examples of such values are the 350 × 350 × 350 mm workspace size or the ±0.03 mm positioning accuracy, which can be fitted to most of the machines.

8. Summary

The first half of the article described the modern additive metal printing processes and their possibilities and their prevalence in industry. By reinterpreting the definition of machine tools, it can be concluded that these machines can indeed be considered as machine tools, and in support of this, it has been described how the machine tool morphology and function block diagrams can be used to examine these modern machine tools. By counting the equipment currently available on the market in a knowledge matrix, it has become possible to determine average parameters, which together with the function block diagrams can provide a basis for the design of PBF metal printing machine tools.

REFERENCES

[1] Duda, T. – Raghavan, L. V.: 3D metal printing technology: the need to re-invent design practice. *AI & Society*, Vol. 33, Nr. 2, 2018, pp. 241–252, DOI: 10.1007/s00146-018-0809-9

[2] Mohammed Ali, S. – Bäckström, C.: *Present and future of Additive Manufacturing*. Master's thesis, 2020, University of Karlstadt

[3] Takács, Gy. – Szilágyi, A. – Demeter, P. – Barak, A.: *Forgácsoló szerszámgépek*. Nemzeti Tankönyvkiadó, 2009.

[4] Kiss L.: *Additív fémnyomtató szerszámgépek*. TDK-dolgozat, Miskolc, 2020.

[5] GE: *Blades and Bones: The Many Faces of 3D Printing*. 2013, www.ge.com.

[6] GE: *3D-Printed 'Bionic' Parts Could Revolutionize Aerospace Design*. 2017, www.ge.com