A review of the newest 3D printing technology for metal objects

Przegląd nowoczesnych technologii druku 3D obiektów metalowych

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The article presents the newest technologies of the 3D printing of metal objects. The technologies were classified on account of the way of laying and joining material. The research results are indicated the advantages and the disadvantages of the various methods of joining metal material. There is presented a brief description of the technology of the 3D printing which using a metal material, and lists of manufacturers who offering the device in the technology.

KEYWORDS: 3D printing, metal objects, additive technique

3D printing, which is part of incremental production techniques, has been in use for over 30 years. The pioneer in this field is Charles Hull, who in 1984 developed a technology called stereo-lithography. It consists of curing photopolymers with a beam of ultraviolet rays. In the following years there was an increase in interest in spatial printing. Breakthrough was the last decade when 3D printing was "freed" from the first patent rights that had just expired. In addition, the RepRap (replicating rapid prototyper) project popularized spatial printing techniques for its use - on the basis of free access to device schemas or software. Nowadays incremental techniques are in the field of interest of many industries. Needs, however, are directed towards the use of 3D techniques to create metal objects.

Technology division

The incremental technique of metal objects takes into account: the form of the working material and the way it is combined and fed. Selection of individual solutions determines the type of technology in which the device will work. At present, many 3D printing technologies feature metal objects, and each has unique features. Choosing the best technology depends primarily on the needs of the contractor and ordering 3D objects from metal. These requirements are most often: short time and low production cost, appropriate mechanical properties of the material, high accuracy (faithful reproduction) or geometrically printed models. Fig. 1 shows the author's division of 3D printing technology of metal objects.

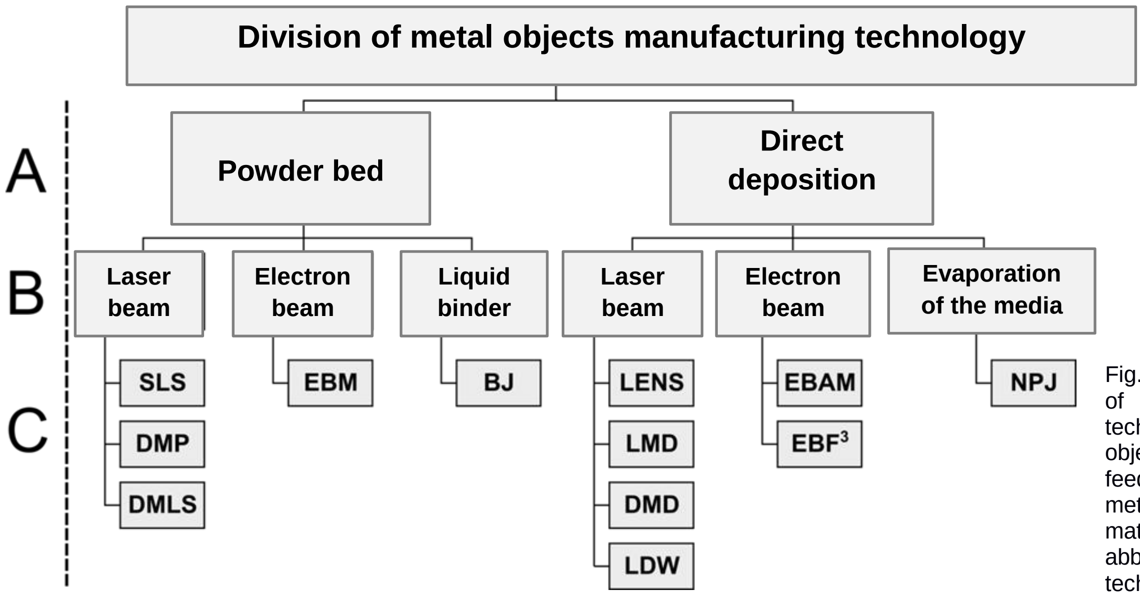

Fig. 1. Classification of 3D printing technology of metal objects (A - method of feeding material, B - method of combining material, C - abbreviated name of technology)

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The main distribution criterion is the method of feeding the material: using a powder bed or direct deposit [1]. Direct point deposition - typical for sintering, melting or surfacing processes - ensures that no residue of uncured powder remains inside the closed solid. The material delivery system through the uniform lining of the powder on the work platform has the advantage that the model does not need to have generated supports. In addition, this method gives you the opportunity to make models of the floor, i.e. in higher parts of the working chamber. Fig. 2 shows a comparison of the described feeding methods.

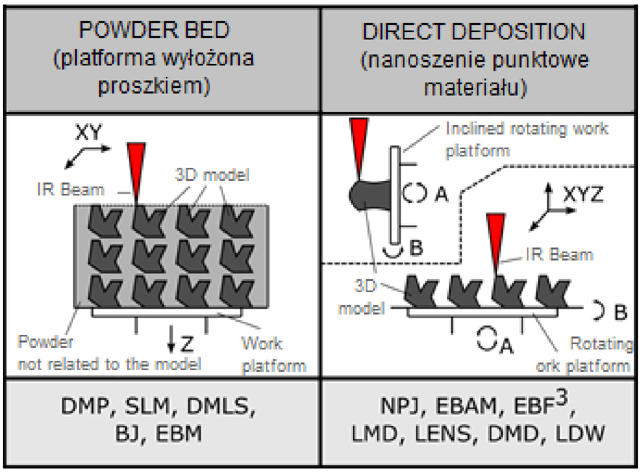

Fig. 2. Comparison of the material handling methods (below the schemes, respective methods are assigned appropriate technologies)

Another method of division is the method of joining the material. Almost all technologies require high temperatures, causing sintering or melting of the material. In methods using laser or electron beams, it is necessary to use a device operating in a gas-tight (or vacuum) chamber [2]. The method of joining material influences the creation of a new classification branch.

Detailed description of the technology

The method of incremental production is characterized by a large variety of methods, methods or forms of metal objects [1]. In addition, many manufacturers - to emphasize the uniqueness of their technical solution - create new names. Typically they are a few letters short for the method name.

The following frequently-cited shortcuts apply to various 3D printing methods for metal objects:

- **SLS** (selective laser sintering) - selective laser sintering (powders of different materials). In this method, the melting of the powder does not take place, but rather by the melting of the powder. As a result of this type of bonding, pore formation may occur, which may adversely affect the tightness or strength of the model [3].
- **DMP** (direct metal printing) - direct metal printing. This abbreviation is used by 3DSystems to describe the entire line of devices for incremental metal objects [2].
- **SLM** (selective laser melting) - selective laser melting (powder of different metals). Stainless steel powders are most commonly used. Unlike SLS, the powder is re-melted by a laser beam, which ensures the leakage of the model (no pores) [1, 4].
- **DMLS** (direct metal laser sintering) - direct metal sintering (powders). The method is based on the same principle as the SLS, but is intended exclusively for sintering powders of various metals [4, 5].
- **BJ** (binder jetting) - jet binder spraying. As a working material, a powder (eg ceramic, plastic, metal) is used as the working material on which the adhesive is deposited. Metallic objects may require an infiltration process to increase density and therefore print strength [3].
- **NPJ** (nanoparticle jetting) - spray nanoparticles. In this method, a mixture of nanoparticles of different metals and a liquid carrier is used as the working material. Together, they form a slurry, which on the model is deposited in the form of drops. There is a temperature of 300 °C in the print chamber for instantaneous evaporation of the liquid media just after being mounted on the model. The method enables the production of single layers of 2 μm height. Patent for this solution is an Israeli company Xjet [2].
- **EBM** (electron beam melting) - electron beam melting. This is one of the methods utilizing the most advanced technology for incremental manufacturing. Printing in the EBM method requires the creation of vacuum conditions in the work chamber. The method allows to make models of high quality (high density) and very good durability parameters [1, 4, 6].
- **EBAM** (electron beam additive manufacturing) - incremental production of electron beam. Like EBM, this method uses an electron beam to melt the material and requires the creation of vacuum conditions. In this case, the wire material is fed directly to the place where it is to be molten [2].
- **EBF3** (electron-beam freeform fabrication) - production of any electron beam form. This method was developed by NASA to print gravity zero gravity models. The same production concept was created in 2001 [7].
- **LC** (laser cladding) - laser welding. This method involves local application of the material - in the form of powder or wire - and sintering / melting with a laser. It is used for the creation of new facilities and the repair/regeneration of damaged or worn machine parts, e.g. by applying an additional layer to the cavity [7]. Shortcuts like LMD, LENS, DMD and LDMD relate, to a greater or lesser degree, to the LC method [1] [9].
- **LDW** (laser deposition welding) - laser deposition by welding. Abbreviation refers mainly to methods related to the repair or modification of existing objects. DMG MORI is one of the manufacturers of this equipment [2].
- **LMD** (laser metal deposition) - laser metal deposition. The method is a specific solution for laser LC. It may consist of powder or wire material and is then labeled as LMD-p (powder, powder) and LMD-w (wire, wire) [1].
- **LENS** (laser engineered net shaping) - laser of final shape and dimension. The method is a specific solution to the LC laser, and has been developed and patented by Sandia Corporation. LENSTM is trademarked by Sandia Corporation [8].
- **DMD** (direct metal deposition) - direct metal deposition. This method is a specific solution for the laser LC method. The DM3D shortcut is used to define incremental solutions of POM Group [2].

The diagrams for each method are shown in Figure 3.

Despite the similarities described in the manufacture of metal objects, manufacturers offer equipment with different operating parameters. The table lists the manufacturers of 3D printing equipment for metal objects.

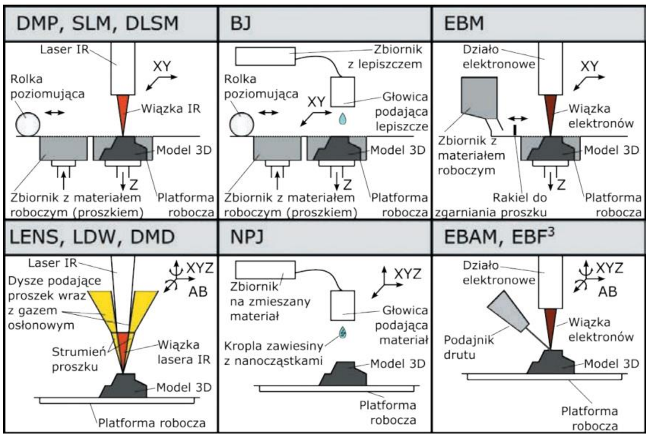

Fig. 3. General diagrams of various 3D printing technologies using metal materials

Laser – Laser
Wiązka – Beam
Model – Model
Rolka poziomująca – Leveling roller
Zbiornik z materiałem roboczym (proszek) – Container with working material (powder)
Platforma robocza – Work platform
Zbiornik z lepiszczem – Container with binder
Głowica podająca lepiszcze – Binder feeding head
Działo elektronowe – Electron gun
Wiązka elektronów – Electron beam
Rakiel do zgarniania proszku – Powder scraper
Dysze podające proszek wraz z gazem osłonowym – Nozzle feeding powder together with shielding gas
Strumień proszku – Powder stream
Wiązka lasera – Laser beam
Zbiornik na zmieszany materiał – Container for mixed material
Głowica podająca materiał - Feeder head
Kropla zawiesiny z nanocząstkami – Drop of the suspension with nanoparticles
Podajnik drutu - Wire feeder

TABLE. Comparison of selected technologies offered by 3D printer manufacturers [2]

Short name	Selected producer	Selected model	Work field	Printing speed	Accuracy
DMP	3DSystems	ProX®DMP 300	250 × 250 × 330 mm	no data	±0,1÷0,2% przy min. ±50 μm
SLM	SLM-Solution	SLM®280HL	280 × 280 × 365 mm	up to 55 cm^3/h	80÷115 μm*
DMLS	EOS	EOS M 290	250 × 250 × 325 mm	do 420 m/min	100 μm*
BJ	ExOne	M-Flex®	400 × 250 × 250 mm	about 30÷60 s/layer***	63,5 × 60,0 × 100,0 μm (*XYZ*)
NPJ	XJet Ltd.	sale since 2017	500 × 250 × 250 mm	no data	2 μm **
EBM	Arcam	Arcam Q20plus	350 × 380 mm (⌀× height)	480 km/min	140 μm *
EBAM	Sciaky Inc.	EBAM™ 68	711 × 635 × 1600 mm	3,18÷9,07 kg/h	–
LDW	DMG MORI	LASERTEC 65 3D	500 × 399 mm (⌀ × height)	1 kg/h***	1,5÷2,5 mm *
LMD	TRUMPF	TruLaser Cell 3000	600 × 420 × 520 mm	85 m/min	15 μm
LENS	Optomec	LENS MR-7	300 × 300 × 300 mm	3,6 m/min, up to 100 g/h	± 25 μm
DM3D	POM Group	DMD105d	300 × 300 × 300 mm	2 m/min	–

* Diameter of beam focus ** The manufacturer only specifies the thickness of a single layer *** Time per layer depending on the material

Conclusions

The continuous development of the technique has resulted in the emergence of new methods of manufacturing metal objects. These objects are present not only in the role of prototypes but also in the fully functional elements of machines or devices. A multitude of technological solutions allows you to choose a 3D printer as you need it. To summarize the presented overview of 3D printing technology for metal objects, the following conclusions can be drawn:

The best print quality (reproducibility accuracy) can be obtained with the NPJ technology (2 μm = layer), which is currently in the test phase. The other technologies have a much lower accuracy in Z axis mapping.

The highest printing speed is EBAM. The manufacturer claims that his device can reach speeds of 9kg / h.

The highest fill density, which translates into mechanical strength, can be obtained in EBM technology. It uses accelerated electrons in the vacuum for melting and combining the powder. An additional advantage of this method is the high purity of the material (which results from the bonding of the material under vacuum conditions).

The size of printed objects depends on the technology and the available printer model. The space in which the metal object can be printed has a minimum dimension of 250×250×325 mm (EOS M 290).

Some of the technologies allow for the regeneration or superstructure of layers on metal objects. These include EBAM, LDW, LMD, LENS and DM3D.

The LASERTEC 65 3D from DMG MORI is a combination of a printing and cutting machine. During operation, the device can deposit metal layers and perform cutting (one operation at a time). The advantage of this solution is the ability to make smooth surfaces inside a metal object.

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