The possibility of manufacturing charge components under battlefield conditions [1]

Možnosť výroby nábojových komponentov v bojových podmienkach

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Abstract:

There is a huge demand in the field of operations for spare parts and, in many cases, for custom-made products that support effective combat. 3D printing can greatly assist in this, and modern devices are capable of manufacturing special objects on or near the battlefield. In this article, I will present four such technical devices that are optimized for these tasks. I will also present the general requirements for such devices and summarize their potential applications for the production of high-quality explosive components.

Keywords: *additive, 3D printing, military, manufacturing technology*

Abstrakt:

V oblasti operácií existuje obrovský dopyt po náhradných dieloch a v mnohých prípadoch aj po výrobkoch na mieru, ktoré podporujú efektívny boj. 3D tlač môže v tomto smere výrazne pomôcť a moderné zariadenia sú schopné vyrábať špeciálne predmety na bojisku alebo v jeho blízkosti. V tomto článku predstavím štyri takéto technické zariadenia, ktoré sú optimalizované pre tieto úlohy. Predstavím tiež všeobecné požiadavky na takéto zariadenia a zhrniem ich potenciálne použitie pri výrobe vysoko kvalitných výbušných komponentov.

Kľúčové slová: *aditívna výroba, 3D tlač, vojenský priemysel, výrobná technológia*

INTRODUCTION

Today, we face a multitude of problems that need to be solved. Among other things, climate change, [1] armed conflicts, and challenges related to energy sources make everyday life difficult. These are also significant issues for the armed forces, [2][3] but they are also looking for solutions in areas such as the operational use of artificial intelligence, [4][5] the mass combat use of drones [6] and ways to defend against them, and the increasingly cheap and rapid production of various explosive devices and aerial bombs [7] for new types of delivery systems.

Additive manufacturing can provide solutions in almost all of the areas mentioned above. Nowadays, 3D printing of hydrogels [8] or even titanium [9] is no longer a significant challenge. Of course, it should not be forgotten that this technology also greatly facilitates education and training. For example, authentic explosive devices and other models can significantly improve officer training [10], as well as the quality of general military training (logistics [11], bomb disposal and mine detection troops [12][13] etc.).

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There is also significant demand for these technological solutions during operations. The flexibility that 3D printers can provide to soldiers at or near the point of use is no longer just a dream. Devices that meet these challenges are already available on the market.

Various demolition tasks and deactivations may require custom charges or a small number of demolition components. 3D printers that can be used in harsh environmental conditions can provide an excellent solution for this. In my article, I will present the most important general operational requirements for these devices, and my goal is to introduce a few devices that are suitable for the task.

A MILITARY APPLICATIONS OF 3D PRINTING

3D printing is one of today's industrial solutions. We no longer need to talk about its potential but rather focus on the practical application of the results achieved and their integration into processes. The military may need all the technological solutions offered by additive manufacturing, or at least most of them, because it requires the production of a staggering number and complexity of different parts. This is especially true in areas of operation where significant logistical demands arise during active conflict.

It is not possible to present all of these in this study, so the focus is primarily on Fused Deposition Modelling/Fused Filament Fabrication (hereinafter: FDM/FFF), as well as a few special technological solutions. Unfortunately, due to the limited scope of this study, Stereolithography (hereinafter: SLA) and its variants, as well as Selective Laser Sintering (hereinafter: SLS), will not be discussed, despite their wide range of military applications.

In additive manufacturing, high-quality components are designed using Computer Aided Design (hereinafter: CAD) software. Nowadays, these programs make it possible to create designs optimized for specific technologies, even highly complex ones [14], and they also perform strength calculations for engineers. If we want to optimize objects beyond the basic design options, generative design can also play a major role in the creation of complex geometries. [15] However, the existence of this software and a high level of knowledge of it are not necessarily required for every professional who operates a 3D printer. Digital storage of completed designs can prevent many difficulties in the field, as only the preparation optimized for the specific printer needs to be done.

There are therefore several areas where military applications for 3D printers are possible. Summarizing these, we can identify the following tasks [16]:

- manufacture of replacement or spare parts; [17][18]
- manufacture of components for use in blasting operations (Fig. 1.);
- manufacture of special, unique, or upgraded components;
- manufacture of general and special-purpose tools;
- manufacture of medical devices and prostheses; [19]
- construction of buildings and fortifications;
- manufacture of equipment and parts for educational, training, and preparatory purposes;
- manufacture of food products using additive processes.

Since modern military forces use a wide range of technical equipment, there is a constant demand for spare parts for their operation and maintenance. In the event of armed conflict, this demand increases many times over due to increased use. Eliminating dependence on faltering global supply chains is a fundamental challenge in such cases, which is why it is very important to have the appropriate capacity, capability, and knowledge to replace these parts internally. [16]

The rapid replacement of components also plays an important role in the field of weapons technology. The rapid replacement of vulnerable components of individual weapons provides a significant tactical advantage, which is technically feasible even in the trenches. Flexibility and speed can be the cornerstones of military success. Of course, the manufacture of complex weapon components is also feasible, in which case the combined use of metal and polymer technologies may be the most practical solution. [20]

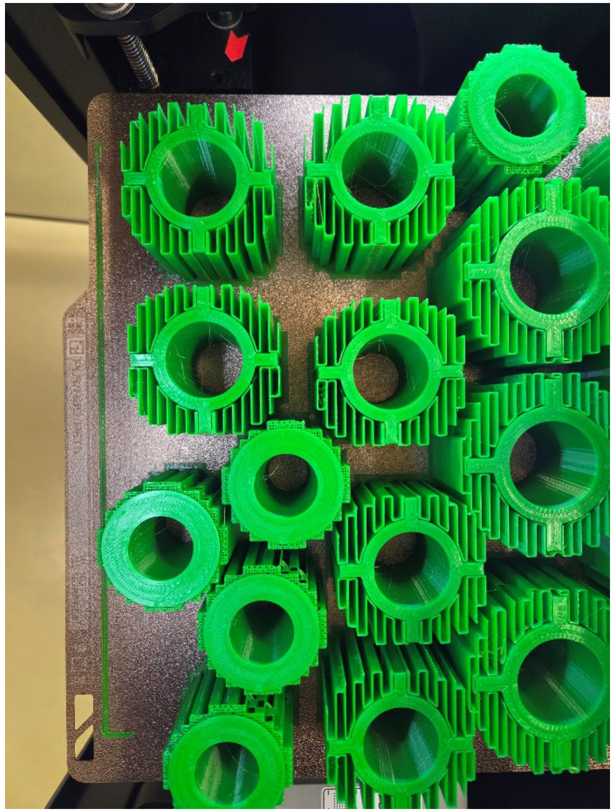

Figure 1: Shaped charge bodies in a build chamber

Source: author's edit.

Highlighting one more area from the above, I must mention the growing demand for custom charges in the field of military technical explosions. The other side of this opportunity is provided by plastic explosives, which are versatile, easy to use, and reliable. With this combination, we can create types of charges that were unknown in military terminology a few decades ago. To summarize the possibilities inherent in this, 3D printing technology can be used to:

- manufacturing of components for cumulative charges (body, liner, etc.) (Fig. 2);
- manufacturing of components for cutting charges;

- manufacturing of components for unique, specially shaped charges;
- manufacturing components for charges used in unique circumstances;
- manufacturing additional elements necessary for securing and positioning various charges;
- elements necessary for securing and positioning detonators.

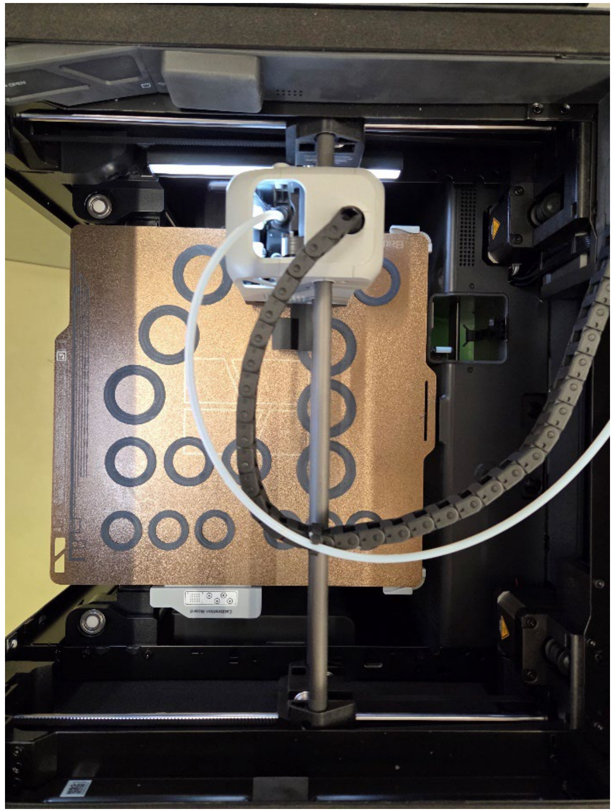

Figure 2: Liner producing process
Source: author's edit.

3D PRINTERS SUITABLE FOR USE IN FIELD OPERATIONS

In this study, we aim to present several types of 3D printers that, based on their manufacturers' specifications, can also be used in the field of operations, without claiming to be exhaustive. The following types are not entirely identical in terms of their application location. Some of them are capable of supporting combat units with their manufacturing capacity in camp conditions, relatively deep in the rear, while other versions can be easily mobilized so that they can even be used to perform tasks on site.

However, it should be emphasized that they have characteristics and capabilities that are essential for use in special circumstances. The most important requirements for battlefield 3D printers are as follows [16]:

- be simple to transport: this depends on size and can be assessed on a case-by-case basis, but it is a basic requirement that it can be transported to locations far from civilian infrastructure.
- not require significant training to operate: all aspects of installation, commissioning, production, and removal should be relatively quick to learn, within a few days;
- it should be easy to use: it should be supplemented with features that facilitate its use, e.g., automatic levelling, monitoring of raw material depletion, continuous monitoring of production (if possible, from a cyber security perspective), prediction of maintenance tasks, etc.
- be designed to withstand the specific conditions of the area of operation;
- be able to cope with the varying pace and workload of military applications;
- be simple to maintain: it should be maintainable even in field conditions, including the replacement of certain key components;
- be simple to repair: preferably not require frequent repairs, which should be possible at or near the installation site (maximum a few hundred kilometres' away);
- its power supply must be secure under military operational conditions;
- if possible, it should be equipped with an uninterruptible power supply unit capable of at least pausing and safely saving the manufacturing process in the event of a power failure;
- it should be optimized for military requirements in terms of cyber defence.

One printer tailored to military requirements is the Xerion Fusion Factory XS, which is technically a complete production line. Its design is adapted to extreme conditions and offers enhanced protection. It is also easy to transport, as its size and packaging comply with logistics standards. A special feature of the station is that it can produce objects using two types of polymers (Polylactic Acid – hereinafter: PLA and Acrylonitrile Butadiene Styrene – hereinafter: ABS), but the device also allows the manufacture of metal (copper and steel) and ceramic parts. In the case of the latter two types, production takes place in several stages because the binder in the filament must be removed from the component. The solution to this is a debinder/sinter furnace unit, in which the process can be carried out safely. The set also includes a cooling station. The sintering process for metals takes place in an N2/H2 protective gas environment, which is not necessary for ceramic components, where the presence of air is required. [21]

Key technical parameters of the production line [21]:

- external dimensions of the 3D printer: 686 x 1029 x 1181 mm;
- printhead design: dual nozzle;
- build volume: 100 x 200 x 100 mm;
- filament diameter: 1.75 mm;
- raw materials: PLA, ABS, stainless steel (316L and 17-4 PH), copper (Cu), ceramic (AI2O3);
- external dimensions of the debinder/sintering furnace: 686 x 1029 x 870 mm;
- maximum sintering temperature: 1550 °C;
- internal dimensions of the sintering furnace: 80 x 150 x 70 mm;
- external dimensions of the cooling unit: 686 x 1029 x 508 mm;

- power of the cooling unit: 2000W;
- power requirements: 230V, 10A.

One type of 3D printer that can be used in the field of defence is Cold Spray Additive Manufacturing (hereinafter: CSAM). Ukrainian soldiers received such printers, which were provided to them by the Australian manufacturer SPEE3D Pty. Ltd. [22] This company also manufactures printer types specifically for military use, which can be used to eliminate difficulties and obstacles in supply chains. The process itself is not revolutionary, but its implementation makes the method particularly innovative. The main features of the XSPEE3D 3D printer, optimized for military use, are as follows [23]:

- possible dimensions of manufactured parts: ~1000 x 700 mm (based on the largest diameter);
- maximum weight of manufactured parts: 40 kg;
- raw materials: aluminum, aluminum bronze, stainless steel, nickel carbide, copper, titanium;
- deposition size: 6 mm;
- input file format: ".stl";
- manufacturing speed: up to 100 g of raw material per minute;
- power consumption: 415 V (3 phases);
- design: developed for field use;
- placement: in a 20-foot standard container;
- weight: 10 t;
- colour: olive green.

During production, fine metal particles are fed into the construction site at supersonic speed (3–4 Mach) through a nozzle. The nozzle is immobile, but the build tray is mounted on a multi-jointed robotic arm that can move at high speed and with a high degree of freedom in three dimensions. This method allows relatively large and heavy objects to be produced in a matter of hours. In addition to its speed, a characteristic feature of this technology is that the surfaces of the final parts may require post-processing. [23]

This additive manufacturing method requires significant space, but its design allows it to be used in the field of operations. Although its colour is not relevant because it can be easily modified, the manufacturer chose it to meet military requirements, as did the standard container-mounted design. This solution can also significantly reduce logistical burdens, as transport equipment is also standardized to this size in most cases. [16]

One of the most outstanding tools for applying traditional FDM/FFF technology in the field is Craitor FieldFab. Its impact-resistant design makes it suitable for use in extremely harsh conditions, and it can even be used for manufacturing during transport. According to the manufacturer's instructions, it is extremely easy to use and can be mastered in 15 minutes, which is an astonishingly quick process. The 5-minute setup time is also insignificant compared to the work performed by the device, and it can be easily moved by two soldiers. The product complies with the most important standards (MIL-STD-810H, AS9100D / ISO9001) and has integrated quality assurance software. An additional advantage is that it has been optimized for the use of multiple bases and special technical quality raw materials. [24]

Key parameters of the device [24]:

- printhead temperature: < 500°C;

- printer tray temperature: < 200°C;
- build chamber heating: < 80°C;
- build volume: 280 x 280 x 280 mm;
- supported materials: PLA, PETG, ULTEM, TPU, Nylon-CF, Nylon;
- power: 1200W;
- power requirements: 80—264V, 10A max.

Another device with special capabilities designed for field use is the Markforged X7 Field Edition. This printer also uses the widely used FDM/FFF technology, but it has a very valuable extra feature. The higher material properties of the manufactured parts are not only ensured by the micron-sized carbon fibers mixed into the nylon matrix, but also by the possibility for the user or designer to integrate continuous fiber reinforcement into the objects. [25] Certain properties of parts with high tensile strength or high bending load capacity rival those of aluminum, but of course, the cost of the raw material is not insignificant. However, this latter factor cannot be a consideration in the field of operations, where supplying combat soldiers is a top priority. [16]

The main features of the X7 Field Edition printer are as follows [26]:

- build chamber dimensions: 330 x 270 x 200 mm;
- overall dimensions: 914 x 914 x 762 mm;
- gross weight: 86 kg;
- power consumption: 100–240 V;
- design: reinforced for field use;
- storage: in a carrying case;
- build layer height: 50–250 µm;
- matrix materials: white or micro carbon fiber reinforced polyamide (in several versions);
- continuous fiber reinforcement: aramid, glass fiber (two versions), carbon fiber (two versions).

When processing 3D objects exported from CAD designs, Markforged Eiger software makes suggestions for fiber reinforcement placement at critical points [27] and even makes recommendations for the placement of inserts in order to achieve higher strength factors.

All of these tools are suitable for providing adequate support to units operating in the field of operations and on the battlefield. Although they have different capabilities, procedures, and raw materials, all of them are capable of performing complex manufacturing tasks under extremely difficult conditions.

SUMMARY

It has been proven that devices capable of additive manufacturing for use in the field are available on the market. I have outlined their most important requirements in order to meet military expectations.

Each of the devices presented has special capabilities and has been optimized for use in difficult terrain conditions. The special and essential raw materials used make them suitable for the

production of high-quality explosive components. Last but not least, soldiers performing demolition tasks can use these devices to manufacture components in a matter of hours after on-site measurements, while others carry out their preparatory tasks.
The technology is promising and still has great potential. Further research could focus on similar analytical and review studies of other technologies, among which photopolymers could be particularly promising.

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