

## Modularity of component systems and materials for their manufacture and use of 3D printer mechanics for plasma cutting

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**Abstract.** In recent years, 3D printing technology has become increasingly widespread and continues to gain popularity. Undoubtedly, we can expect to see the widespread adoption of additive manufacturing techniques in the future, but the practical application of 3D printing is already available to everyone today.

The authors of this article consider possible options for implementing a modular hotend mounting system for a 3D printer. They consider possible options and advantages compared to traditional hotend mountings that exist today. They test such a mounting system on an experimental stand created with the mechanics of a 3D printer.

During continuous operation of a 3D printer, it is often necessary to clean the hot end, which means constantly stopping the printer for a certain amount of time. It may also be necessary to replace the nozzle diameter in the extruder itself. Sometimes it is also necessary to quickly change different types of plastic. According to the authors, such a modular mount can speed up the hotend maintenance process. In the future, aluminum-based options are proposed as the material for manufacturing the body of such a mount. This material has sufficient strength and low weight, which is important for printer mechanics.

Based on this modular mounting system, the authors consider the possibility of connecting other working devices to the printer's mechanics. Among them, it is proposed to develop a working body based on a plasmatron. For this plasmatron option, it is proposed to build it according to the plasma jet

scheme. With this design, an electric arc ignites the plasma inside the plasma torch, and a stable plasma beam emerges through a thin nozzle. The printer's mechanics will allow for precise and even cutting of the material, which, according to the authors, will enable the cutting of metals and their alloys of small thickness. In the future, such application of a plasma torch on the mechanics of a 3D printer will still require experimental testing.

**Keywords:** extruder, direct extruder, hot end, 3D printer, aluminum, silumin, plasmatron, plasma cutting.

### INTRODUCTION

The manufacture of plastic parts of varying complexity using 3D printing is becoming widely used today. Various technical tasks are being solved with the help of 3D printers [2, 9, 10]. These printers can operate for 6, 12, or more hours. Such operation of a 3D printer requires maintenance or repair of its hot end. This may be necessary for various reasons:

1. clogging of the extruder nozzle, which makes it impossible to extrude plastic correctly;
2. Thermal plugging in the extruder's thermal barrier zone;
3. Installation of a new nozzle or replacement with a nozzle of a different diameter;

4. Repair and replacement of the heating block, temperature sensor, heating element;

5. Replacement of one type of plastic with another.

### PURPOSE OF THE PAPER

The purpose of this article is to modernize and improve the designs of the hotend mount for a 3D printer, to implement the possibility of a modular hotend mount for a 3D printer to facilitate maintenance and repair during printer operation, and to implement the possibility of connecting other devices to the printer's mechanics as a working body.

### RESEARCH RESULTS

The large number of different printers creates a wide variety of hotends. Today, there are many different hotends for 3D printers in terms of design and functionality. Depending on the design features of the printer, the hotend itself can be mounted in different ways [1].

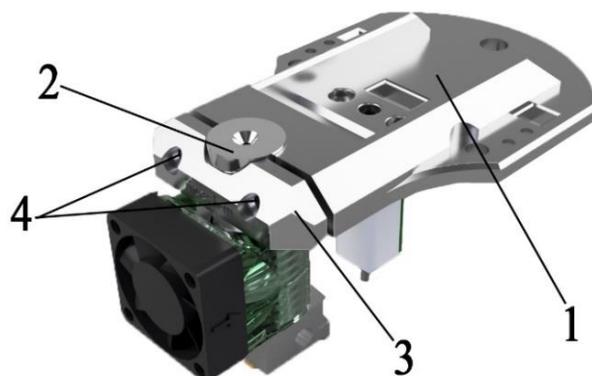
One of the most affordable and widely available hot ends for printers is the E3D V6 (Fig. 1) [4]. Its structure can be divided into two separate parts. The first part consists of a heat sink 1. Plastic is fed into one side of the heat sink, and a heat barrier 3 with a Teflon tube is screwed into the other side. A fan 2 is installed on the radiator for cooling. The second part consists of a heating block 4, which is connected to the cooling radiator 1 through a thermal barrier 3. To heat the block to a specified temperature, it is equipped with a ceramic heating element 5 and a temperature sensor 6.

One option for installing such an E3D V6 hotend on a TEVOUP TARANTULA 3D printer can be carried out using the appropriate platform (Fig. 2) [6]. Platform 1 is part of the Y-axis moving carriage, which is part of the print height portal. The hotend radiator 2 is clamped between platform 1 and clamping plate 3 using bolts 4. In most cases, the control wires are connected to the printer's control board via a flexible cable channel. During operation of the hotend, if it needs to be replaced, the mounting bolts 4 are unscrewed. Assembly is performed in reverse order. This creates

some inconvenience if the nozzle needs to be replaced or cleaned.



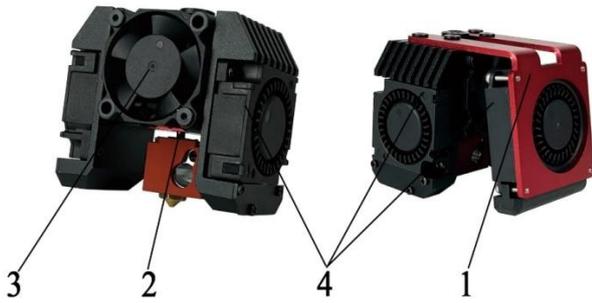
**Fig. 1.** Structure of the E3D V6 hotend: 1 – cooling radiator; 2 – radiator fan; 3 – thermal barrier with Teflon tube; 4 – heating unit; 5 – ceramic heating element; 6 – thermistor (temperature sensor)



**Fig. 2.** E3D V6 hotend mounting platform: 1 – Y-axis carriage platform; 2 – hotend radiator; 3 – clamping plate; 4 – clamping plate bolts

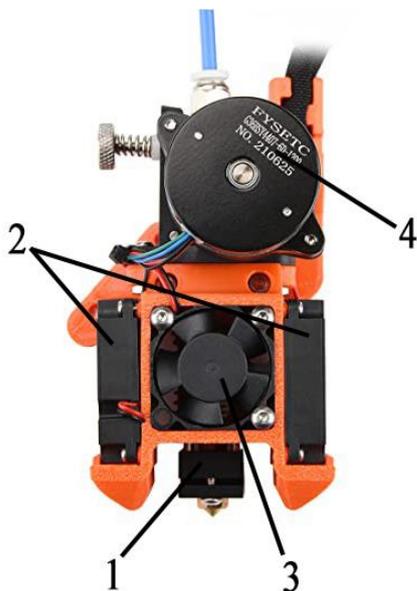
Let's consider another interesting option, the Chow Think Armor 3.0 Hotend Upgrade (Fig. 3) [7]. It is based on a mounting plate 1 on which an extruder 2 is installed together with a radiator and a heating unit. A cooling fan 3 is installed on the extruder radiator. To cool the plastic of the model during printing, additional plastic cooling fans 4 are installed on the plate body. The use of model blowing significantly affects the print quality of various bridges and overhanging parts of the model itself. Also, the technical requirements of some plastics require such cooling to achieve maximum print quality. If disassembly is necessary, the hotend must be completely disassembled or partially disassembled on the printer. This

creates certain inconveniences in servicing the hotend.



**Fig. 3.** Chow Think Armor 3.0 Hotend Upgrade: 1 – hotend mounting plate; 2 – assembled hotend extruder; 3 – radiator cooling fans; 4 – plastic cooling fans

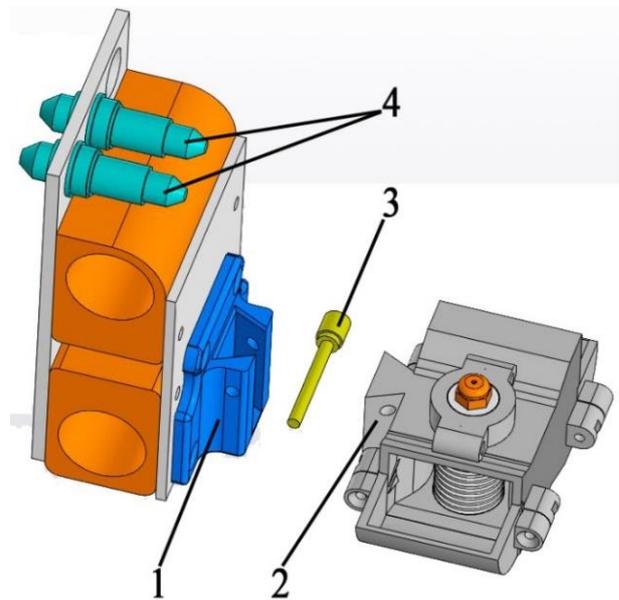
For printing models from flexible plastics, it is most expedient to use a hotend based on direct extruder technology. An example of such a hotend is the BIQU H2 extruder (Fig. 4) [8]. It consists of a heating block and radiator 1, a radiator cooling fan 2, and two fans for cooling the plastic 3. One of the features of such hot ends is a built-in plastic feed system 4, which is located above the radiator to feed plastic into the extruder itself.



**Fig. 4.** BIQU H2 Extruder: 1 – heating unit with radiator; 2 – radiator cooling fan; 3 – plastic cooling fans; 4 – plastic feed system

The hotends considered have a variety of structures and designs. Each of them has its own sequence of disassembly and replacement

of components, which may be necessary for maintenance during operation. The hotend control wires are directly connected to the control board. This connection is reliable in operation, but creates a lot of inconvenience when servicing individual parts of the hotend. In the event of failure of any element of the hotend, it is necessary to disassemble the entire cable channel to replace it. In this regard, it is interesting to modernize the 3D printer for a hotend modular system. A modular hotend connection was developed for the stand as a test sample. The E3D V6 extruder was taken as a basis (Fig. 5).

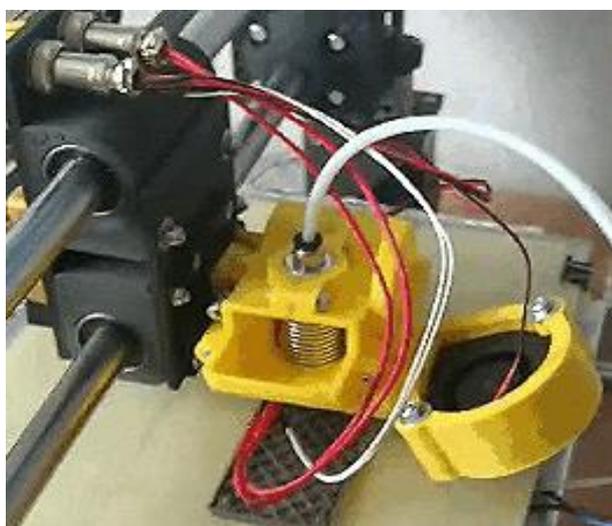


**Fig. 5.** Modular hotend mounting system: 1 – platform with trapezoidal groove; 2 – E3D V6 extruder in a housing with a trapezoidal groove; 3 – hotend fixing bolt; 4 – MIC type wire connection

In this modular mounting system, the fasteners were designed for platform 1, which has a trapezoidal groove. For the E3D V6 extruder, a housing 2 was created with a similar trapezoidal groove for connecting them. This trapezoidal shape allows the two parts to be tightly connected along the entire length of the groove. To limit their movement, a fixing bolt 3 is used, which additionally presses the sides of the platform grooves against the hotend groove, creating a fixed, strong connection. For the convenience of quick connection of the hotend control wires, MIC 4 connectors are used in this design, which ensure a reliable connection.

If you need to replace the hotend, you only need to follow two steps. First, disconnect the control wire connectors. Second, unscrew the fixing bolt and disconnect the hotend from the platform. Install the new hotend in reverse order. This modular mounting system allows you to quickly change and service the hotend of a 3D printer. This is convenient if you have several printers. You can also have hotends of different designs and purposes. The main condition is that they have the same shape of connection slots.

The Department of Vocational Education at Kyiv National University of Construction and Architecture designed and assembled an experimental stand with the mechanics of a 3D printer, which is used in the educational process (Fig. 6) [5]. Using 3D printing on this printer, a test variant of such a modular hotend mount was printed. PLA plastic was chosen for printing the mounting bracket body. This plastic has excellent physical and mechanical properties and is easy to print. It is well suited for prototyping and experimental testing of the modular mounting system before manufacturing it from metal.



**Fig. 6.** Fastening the hotend of a 3D printer during testing

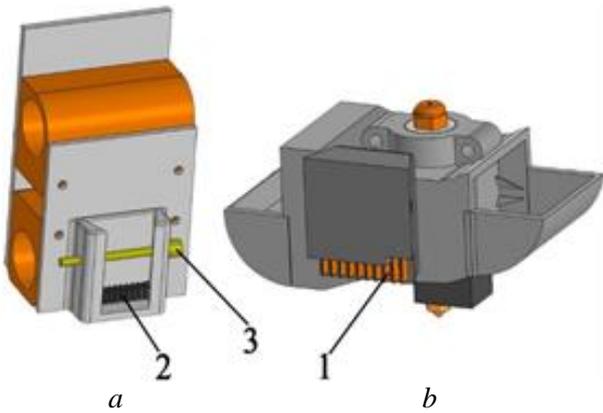
Since plastic is less durable than metal, it would be advisable to manufacture such fasteners from aluminum alloy in the future. The most common alloy grades available are: 2024 T351 (or D16T), B93, B95 are high-strength, heat-treated aluminum alloys with copper,

magnesium, and manganese, which are used in aircraft construction, mechanical engineering, and other industries where strength and lightness are important. This material has sufficient strength and is well suited for the manufacture of a modular mounting system for a 3D printer. However, when modernizing a 3D printer in this way, the specific mechanical characteristics of the printer must be taken into account. If the total weight of such a mount is too great, it will create an excessive load on the printer's mechanics. It is advisable to use AK9 silumin as the material. This is an aluminum alloy with silicon, in which silicon reaches 9%. This alloy has good casting properties and strength, and is lighter than the previous material (Table 1). This can minimize the weight of the future hotend mount.

**Table 1.** Properties of aluminum alloys

| Properties                         | 2024 T351 | B93     | B95     | AK9     |
|------------------------------------|-----------|---------|---------|---------|
| Ultimate tensile strength, MPa     | 420       | 500-530 | 570-600 | 196-245 |
| Yield strength, MPa                | 325       | 400     | 550     | 100-130 |
| Relative elongation, %             | 19        | 7-12    | 11-14   | 0,5     |
| Density, g/cm <sup>3</sup>         | 2,78      | 2,8     | 2,85    | 2,64    |
| Hardness according to Brinell, MPa | 1200      | 1500    | 1500    | 700-900 |

During testing of the preliminary design of the modular mounting system, the task arose to simplify the disconnection and connection of the hotend to a single step. To solve this problem, it is proposed to retain the trapezoidal shape of the groove as a basis, but to modify it slightly (Fig. 7). A block of contact plates 1 is placed in the lower part of the trapezoidal groove of the hotend (Fig. 7,b). There are ten contact plates, all of which are divided into separate paired blocks.

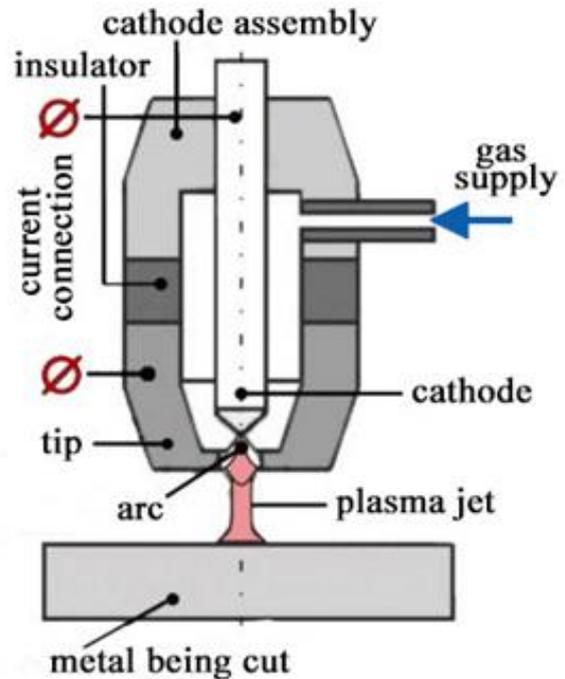


**Fig. 7.** Project “Modular hotend mounting system”: *a* – mounting platform with hotend locking bolt; *b* – hotend with trapezoidal groove and connection contact block

To connect certain parts of the hotend in the Bowden hotend system, the large plates are responsible for connecting the ceramic heating element, which heats the nozzle assembly. The next four plates are responsible for connecting the wires of the extruder radiator cooling fans and the controlled plastic cooling fan of the model. The next pair of contact plates are responsible for connecting the nozzle heating temperature sensor. The last four plates are used in the direct extruder system to connect the plastic feed motor wires. The mounting platform (Fig. 7,a) has a similar trapezoidal groove at the bottom of which there is a block of contact slots 2 for connecting the hotend contact plates. At the top of the platform there is a fixing bolt 3 for secure fastening of the hotend itself.

The implementation of such a modular hotend mounting system in a 3D printer makes it possible to connect other devices in the future using the printer's mechanics. With an experimental stand available, it is proposed to connect a plasmatron [11, 12] as a working body for research. Due to the small working area of the printer, it is planned that the thickness of the metal for cutting will not exceed 3.5 mm. The plasmatron itself is a device that creates a high-temperature, ionized plasma jet for processing materials, most often for air-plasma cutting (steel, aluminum, copper) and electric welding. It works by converting a stream of compressed air into plasma under the action of an electric arc, which allows for high preci-

sion, cutting speed, and clean cuts without deformation. It is planned to use the plasma torch according to the diagram (Fig. 8).



**Fig. 8.** Plasma jet cutting diagram

In this scheme, compressed air is first fed into the plasma torch at a pressure of up to 6 bar. Then an arc is ignited between the electrode and the nozzle. The air flow passes through the electric arc, ionizes, heats up to ultra-high temperatures, and turns into plasma. The directed plasma flow bursts out through a narrow nozzle at high speed, melts the metal, and blows it out of the cutting zone, creating a neat and precise cut. To connect such a plasma torch, it is necessary to develop a mounting device based on the principle shown in Figures 5 or 7.

## CONCLUSIONS

The article discusses various types of hotends based on the E3D V6 extruder. They differ in design and external structure. With prolonged use of a 3D printer, it becomes necessary to service its hotend. This requires disassembling the hotend completely or partially, and in most cases on the printer itself. This creates certain inconveniences in the operation of a 3D printer.

The most interesting feature is the modular hotend system, which facilitates the maintenance of the 3D printer extruder. It is based on an easily detachable connection between the hotend and the printer platform. For reliability, this connection uses bolt fasteners. For convenience of connecting wires, easily detachable MIC-type connections are used. During operation, this modular mounting system made it possible to quickly and easily replace the printer's hotend. This is especially useful if there are several hotends, as while one hotend is working, the other is undergoing maintenance.

They are also considering the possibility of further modernization of such a modular hotend mount. By combining a detachable wire mount with the hotend mounting system itself. Such a modular 3D printer hotend mounting system will make the replacement process more convenient. Aluminum-based alloys are proposed as the material for manufacturing such a mount. This material will ensure sufficient strength and low weight of the mount.

The possibility of using such a modular mounting system in a 3D printer to connect various working bodies is also being considered. As an option, it is proposed to connect a plasmatron as such a working body. This will allow the printer's mechanics to be used for plasma cutting of thin materials. This option for using plasma cutting still requires additional research and experimental testing.

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**Модульність систем комплектуючих та матеріали для їх виготовлення і використання механіки 3D-принтера для плазмового різання**

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**Анотація.** За останні роки поширення технологій 3D-друку набуло, і на сьогодні продовжує набувати, все більшого застосування. Без-

умовно, в майбутньому нас очікує масштабне поширення адитивних методик, але практичне застосування 3D-друку доступно кожному вже сьогодні.

Автори у даній статті розглядають можливі варіанти реалізації системи модульного кріплення хотенда для 3D-принтера. Розглядають можливі його варіанти та його переваги порівняно з традиційним кріпленням хотенда які існують на сьогодні. Виконують тестування такої системи кріплення на створеному експериментальному стенді з механікою 3D-принтера.

Підчас постійної експлуатації 3D-принтера частіше за все приходиться виконувати чистку хотенда що зумовлює постійно зупиняти роботу принтера на певний час. Також може бути необхідність заміни діаметра сопла у самому екструдері. Інколи також є необхідність швидко змінювати різні типи пластику. Таке модульне кріплення на думку авторів може пришвидшити процес обслуговування хотенда. В майбутньому у якості матеріалу для виготовлення корпусу такого кріплення пропонують варіанти славу на основі алюмінію. Такий матеріал має достатню міцність та невелику вагу що є важливим для механіки принтера.

На основі такої модульної системи кріплення автори розглядають можливість підключення на механіку принтера також інших робочих пристроїв. Серед них пропонується розробити робочий орган на основі плазмотрона. Для такого варіанту плазмотрона пропонують побудувати його за схемою плазмового струменю. При такій будові електрична дуга запалює плазму у середині плазмотрона і через тонке сопло виходить стійкий плазмовий промінь. Механіка принтера дозволить виконувати чіткий та рівний різ матеріалу, що на думку авторів дозволить здійснювати різ металу та їх сплавів невеликої товщини. У майбутньому таке застосування плазмотрона на механіці 3D-принтера ще потребує експериментальних випробувань.

**Ключові слова:** екструдер, директ-екструдер, хотенд, 3D-принтер, алюміній, силумін, плазмотрон, плазмове різання.

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