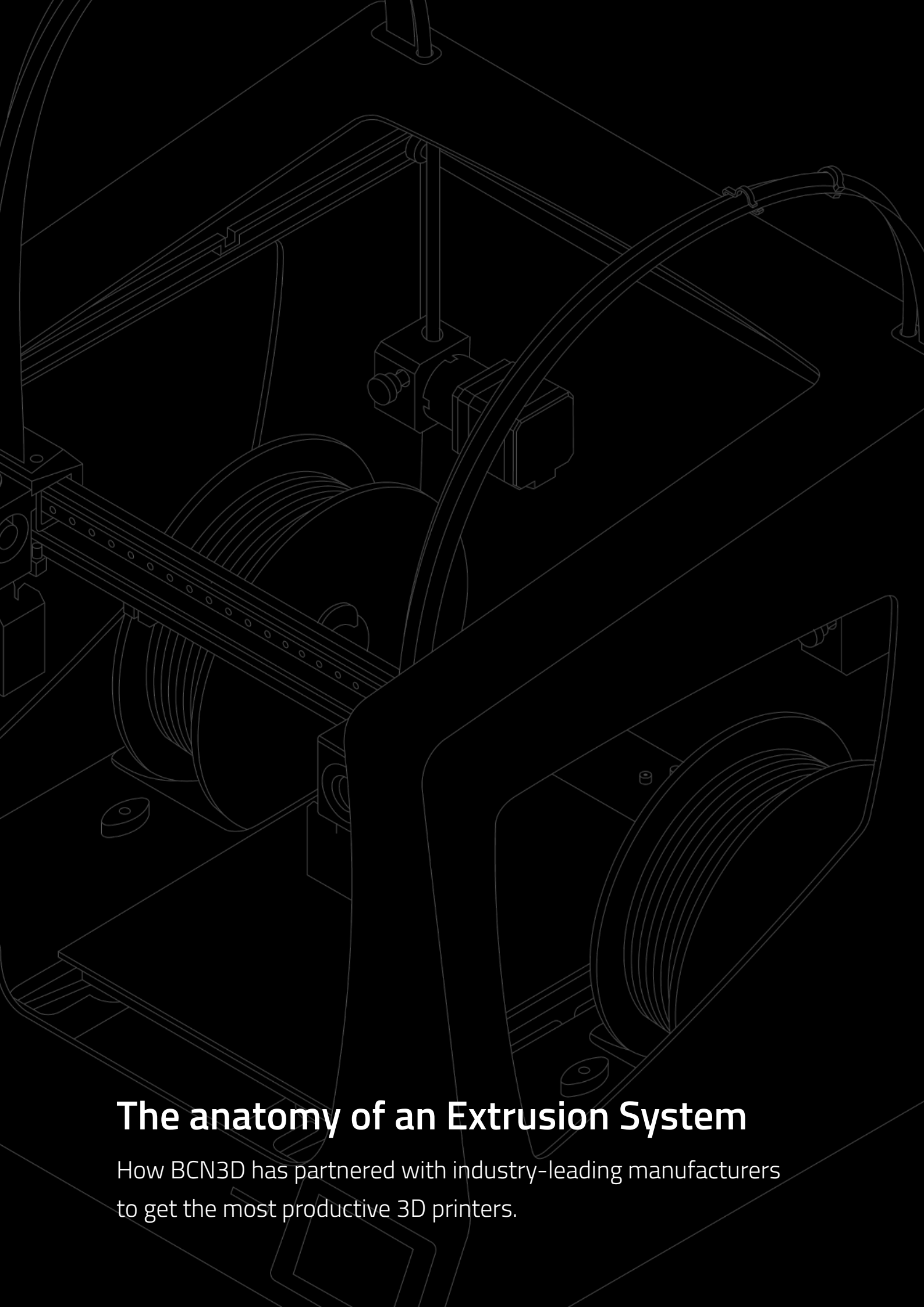




The anatomy of an Extrusion System

How BCN3D has partnered with industry-leading manufacturers to get the most productive 3D printers.

Contents

01

Introduction

02

BCN3D Hotends BY e3D™

03

Bondtech™ Extruders

04

Filament Runout Sensor

05

Conclusion

01

Introduction



This whitepaper is aimed at businesses that may consider introducing 3D printing technology to their facilities and need to know how the extruding system works, especially in what makes the new generation of BCN3D printers unique.

The main focus resides on the new extrusion system incorporated in the BCN3D Sigma R19 and Sigmax R19, composed by top-grade industry-leading components: Bondtech™ Extruders, BCN3D Hotends by e3D™ and Filament Runout Sensors.

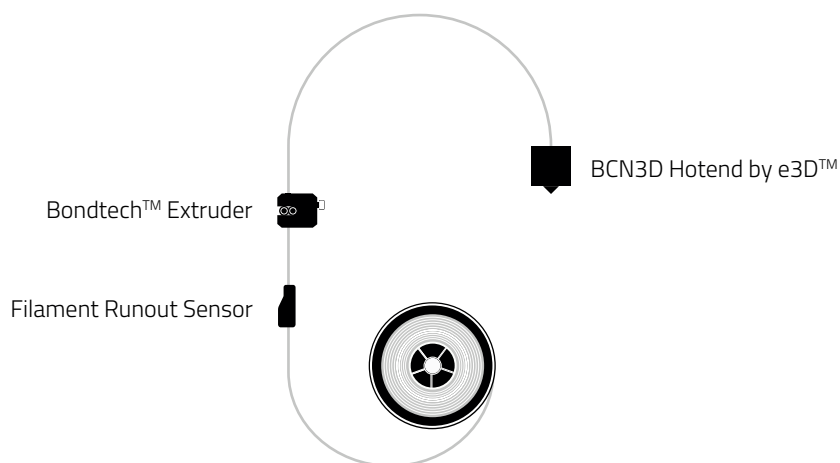
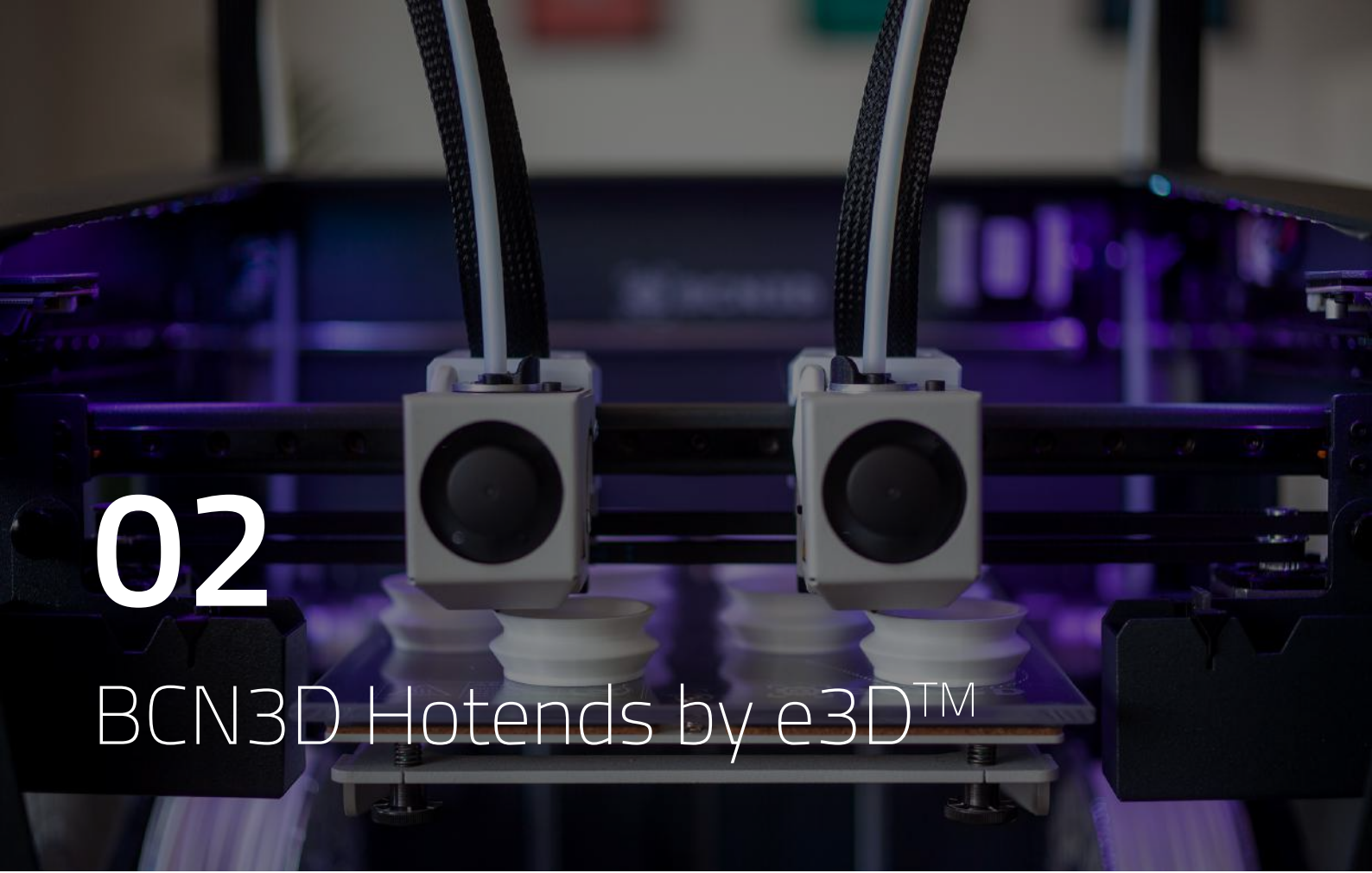


Figure 1. BCN3D Extruder System simplification.

How does it work?

The Extruder System takes the raw material from a spool, makes it go through the Filament Runout Sensor, which will pause the active print in case of detecting a lack of filament, and enters into the Bondtech™ Extruder. This last mechanism pushes and pulls the filament to feed the e3D™ Hotend, the part that melts the filament to deposit it layer by layer.



02

BCN3D Hotends by e3D™

The hotend can be described as the component of an FDM 3D printer that heats, melts and extrudes the material layer by layer through a nozzle. The whole structure of the hotend helps to maintain a consistent and accurate temperature as well as providing an optimized thermal dissipation.

Before deeply analyzing the main aspects of e3D™ hotends, some aspects of plastic filaments need to be taken into account.

First of all, plastic is a combination of a polymer and additives. A polymer can be described as a material made of long and repeating chains of molecules. All these chains can modify their viscous behaviour depending on the temperature. At this point, in most of the polymers¹ there are two critical temperatures: Glass Transition Temperature and Melting Temperature.

- Glass Transition Temperature (T_g)

When a polymer is below this temperature, it is in a semi-crystalline state and its chains have no mobility. Beyond the T_g , it turns to a rubbery state, expanding itself and the chains gain some mobility.

- Melting Temperature (T_m)

At higher temperatures, there is another transition point which is the Melting Temperature Point (T_m). At this temperature, the polymer turns from solid to liquid, so it can be extruded easily as the chains break.

¹Some polymers do not have a T_g / T_m .

Once introduced the polymers, the common parts of most hotends are described:

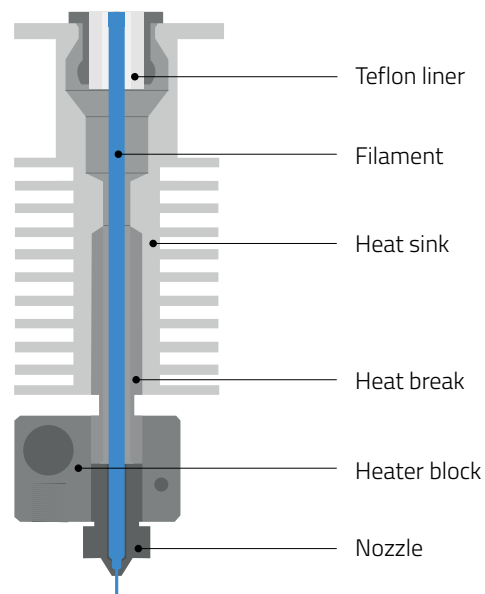


Figure 2. Parts of a hotend.

- *Nozzle*: the part where melt filament comes out of the hotend. The size of the nozzle defines the resolution in the XY plane and, therefore, the print quality.

- *Heater Block*: joins the nozzle to the heat break and holds the heater cartridge and thermistor.

· *Heater Cartridge*: This component heats up the hotend.

· *Thermistor*: This part senses the temperature of the heat block.

- *Heat Break*: A thin cylinder that connects the heat block to the heat sink. It acts as a thermal resistance. It is made of stainless steel for its low thermal conductivity.

- *Heat Sink*: Cools down the cold part of the hotend using a fan and lateral fins. It is made of aluminium to easily dissipate the heat through the fins.

- *Teflon Liner*: PTFE liner that guides the filament into the hotend.

The hotend schema shown can be simplified² into three zones where the temperatures range is different.

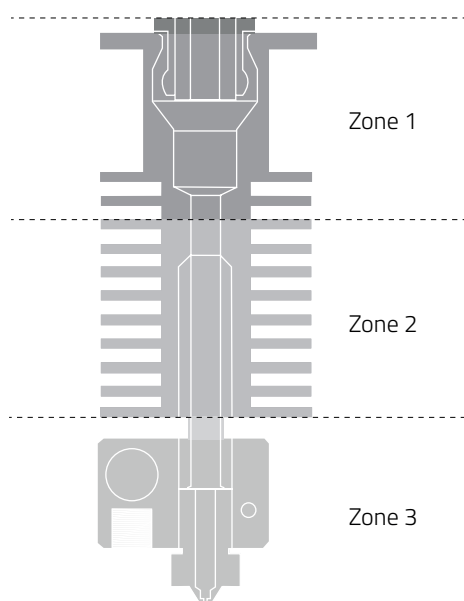


Figure 3. Zones distribution based on the temperatures along the hotend.

Zone 1: Below T_g . The transportation zone, where the polymer needs to be cold in order to avoid frictions against the wall. If beyond T_g , the polymer expands and collides with the Bowden tube walls.

Zone 2: Between T_g and T_m . It is a transition zone where the behaviour cannot be easily predicted. Some frictions appear as the polymer expands.

Zone 3: At T_m . Melting zone, which needs to be as homogeneous as possible. Temperatures beyond and below generate over-melted and non-melted plastic, respectively.

When designing a hotend, defining an internal geometry that optimizes the extrusion process is vital. The control of the temperature and the pressure through this geometry can ensure a fluid and constant extrusion of plastic. e3D™ company, who has designed and manufactures the new BCN3D hotend, has created a top-grade component for BCN3D printers thanks to their proven experience and knowledge in hotend' engineering in the last years. e3D™ has designed an internal and external geometry that holds a constant temperature at the zone 3, reduces the zone 2 to avoid friction and enlarges the zone 1 where the behaviour of the plastic can be easily predicted. Meanwhile, other hotends cannot reduce the transition zone, ending up with clogged hotends or under-extrusion problems.

As has been said, the main critical zone of polymers can be found between T_g and T_m , as the polymer expands and it creates a friction force against the hotend walls. That means the polymer itself is resisting to be extruded. Besides, the thermal behaviour of it can be difficult to predict, and that makes the calculations a bit more complex.

² This simplification does not take into account the polymers that do not have a T_g , or it is below Room Temperature.

Comparison

e3D™ hotend assembled on BCN3D printers will be thermally compared to a standard hotend. How heat is transferred through the hotend defines the difference in quality and reliability between hotends.

The reliability of a hotend can be calculated through the temperature difference between the target temperature expected and the real temperature reached by the hotend. Every hotend has its own structure to conduct the heat so by fabrication tolerances there will always be a tolerance when calculating the real temperature.

As shown in the following distribution, BCN3D Hotends by e3D™ temperature differences are compared to the ones from standard hotends. Test conditions were PLA heated at 220°C.

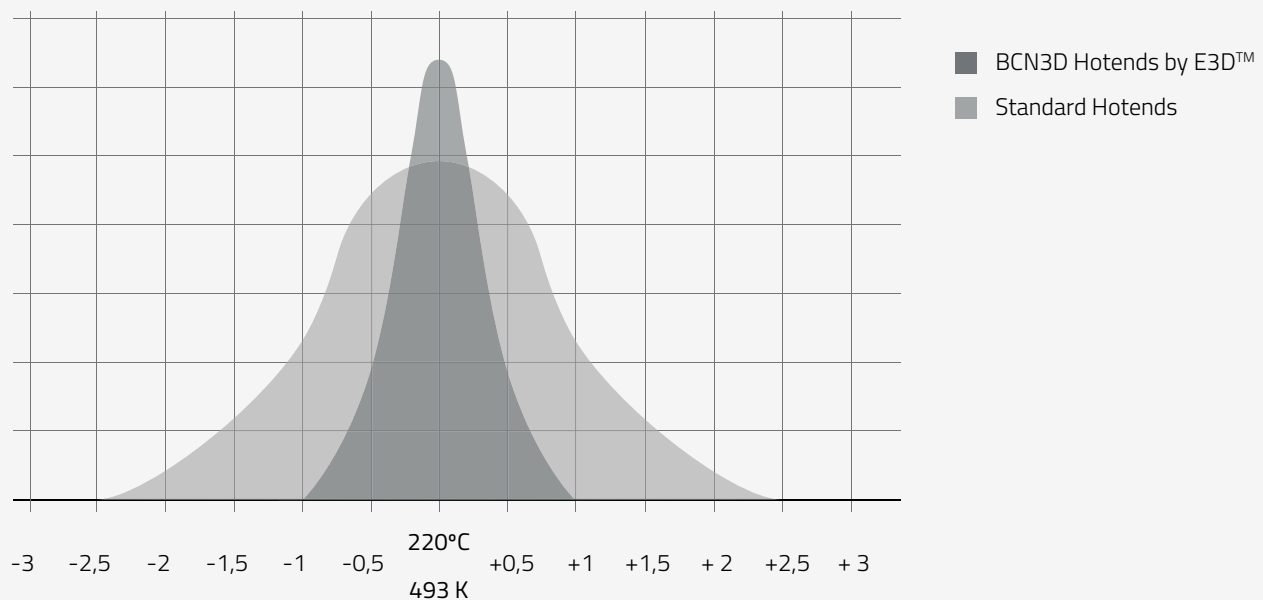


Figure 4. Comparison between BCN3D Hotends by E3D™ and Standard Hotends in terms of accuracy. The curve for each type of hotend refers to distribution of the population.

It can be seen that e3D™ hotends have considerably tighter tolerances than standard hotends, having at maximum a difference of $\pm 0.5^\circ\text{C}$. Almost the majority of these hotends have no meaningful difference from the real temperature. Meanwhile, a standard hotend can be at $\pm 2^\circ\text{C}$ from the real temperature.

When this accuracy has tight tolerances for all hotends, it ensures each printer will behave exactly the same way in terms of printing experience. That means the printing profiles that BCN3D engineers prepare at their facilities, will perfectly work in all BCN3D printers.

The tolerances difference is mainly due to the heat transfer between the elements of the hotend, especially the heater cartridge and the heat block. In the case of e3D™ hotends, there are less thermal resistances between them and the heat flow is more fluid. Besides, this fact favors a more constant temperature all over the heat block and a better 3D printing experience, because avoids the formation of over melted plastic or solid plastic particles.

The heat dissipation, which means the heat transfer from the hottest parts to colder ones, will be now analyzed through thermal simulations. The data collected to define boundary conditions has been obtained by thermal scans. The hottest point is the heat block and the dissipation is necessary to avoid a large transition zone, where the polymer is above T_g and the filament generates friction against the extrusion direction. The test has been done using PLA filament and heating the hotend at 220°C (493 K).³

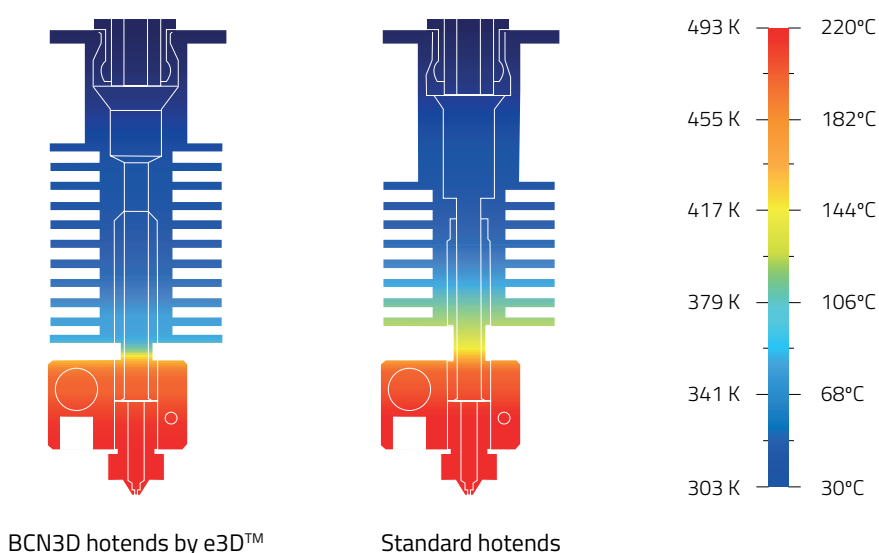


Figure 5. Thermal analysis comparison between BCN3D Hotends by e3D™ and Standard Hotends.

When comparing both hotends, it can be seen that the e3D™ hotend easily dissipate the heat due to a high-performance heat sink and its number of lateral fins, which is considerably higher than a standard hotend without changing the global dimensions of the injector.

That means that e3D™ hotends can reduce the transition zone and have more control over the flow passing through itself. Standard hotends are more likely to have under-extrusion problems when 3D printing, because of the filament friction during the transition zone.

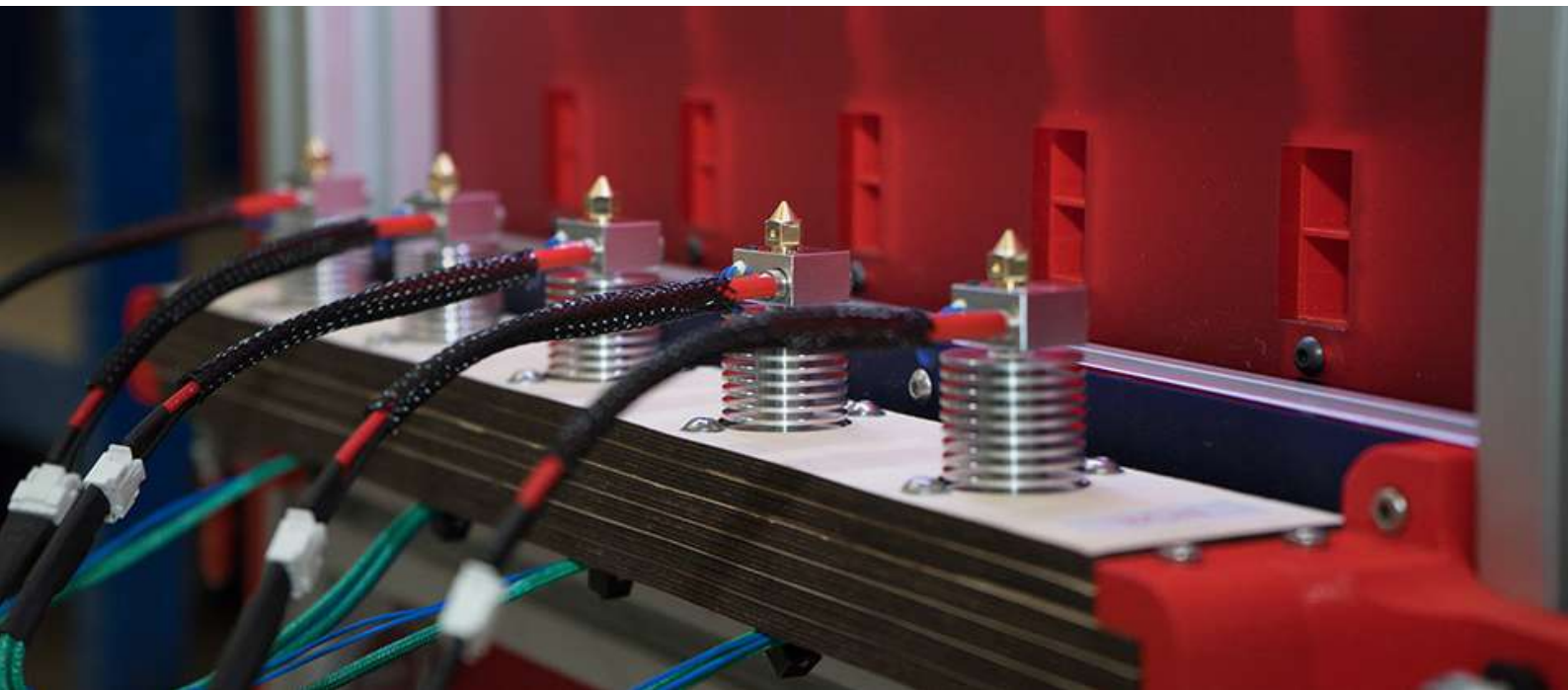
Besides, the PTFE tube that guides the filament inside e3D™ hotend is never subjected to high temperatures, so there is no risk of damage due to overheating.

³The influence of the fan has not been taken into account in order to compare exclusively the performance of the hotend dissipation.

E3D™ know-how

Throughout the brief history of the 3D printing industry, e3D™ has become synonymous with quality and reliability, leading the hotend market. In the last few years, e3D™ has been awarded by 3D Printing Industry and TCT, and has been recognized by The Sunday Times as one of the fastest-growing private technology companies.

E3D™ assembles more than 800 hotends per day, using high-precision machining that gives the hotends one of the highest reliabilities of the 3D printing market. During production, each individual hotend is rigorously tested and then hot tightened by e3D™. E3D™ use its own custom-built assembly equipment to semi-automate the assembly process and conduct quality control to ensure every hotend performs to the same high standard.



This new partnership with the English manufacturer has allowed BCN3D to work closely with the renowned company in order to equip the printers with top-level features in terms of hotends and extrusion systems. The new BCN3D Hotends by e3D™ include the machining and engineering know-how acquired by e3D™, which ensure the highest quality standards. They have been specially designed to be used in BCN3D printers and provide a smooth and reliable extrusion under different printing environments.

03

Bondtech™ extruders

An extruder is a motor and all the associated mechanisms that push and pull the filament to carry it from the spool to the hotend. The main goal in this section is to understand how an extruder works and analyze why Bondtech™ Dual Drive extruders are probably the best ones that are currently in the 3D printing industry.

Extrusion Muscle

The main difference between Bondtech™ and other extruder manufacturers resides on the fact that Bondtech™ system consists of two high precision CNC machined and hardened steel drive gears, while the majority of the brands have only one drive gear. The symmetrical force from two gears helps to secure the filament grip from both sides and minimizes the risk of under extrusion, filament deformation and grinding.

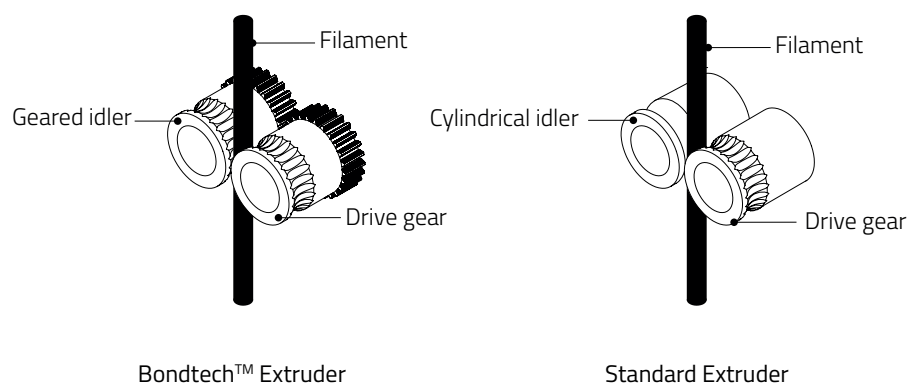


Figure 6. Internal geometry differences between a Bondtech™ Extruder and a Standard Extruder.

The failures listed before are the most common printing troubles due to extruders. They are described below in order to realize the importance of an extruder's good performance and how can they affect the printing reliability.

Under Extrusion

It is possible that there may be less plastic exiting the nozzle than what the software expects, and that will end up with holes in the printed part.

Grinding

The gear has sharp teeth and bites into the filament to push it forward or backwards. If the filament is unable to move due to hotend clogging or slipping inside the extruder and the drive gear keeps spinning, it can grind away plastic from the filament. If the amount is that significant, there may be nothing left for the gear teeth to grab on to.

Filament Deformation

The extruder gear applies pressure on the filament and may end up with a filament deformation if this value is too high. This can imply that the material flow may have variations and affect the final quality.

To fully understand how this difference can affect the features of an extruder, some parts of it⁴ are described below:

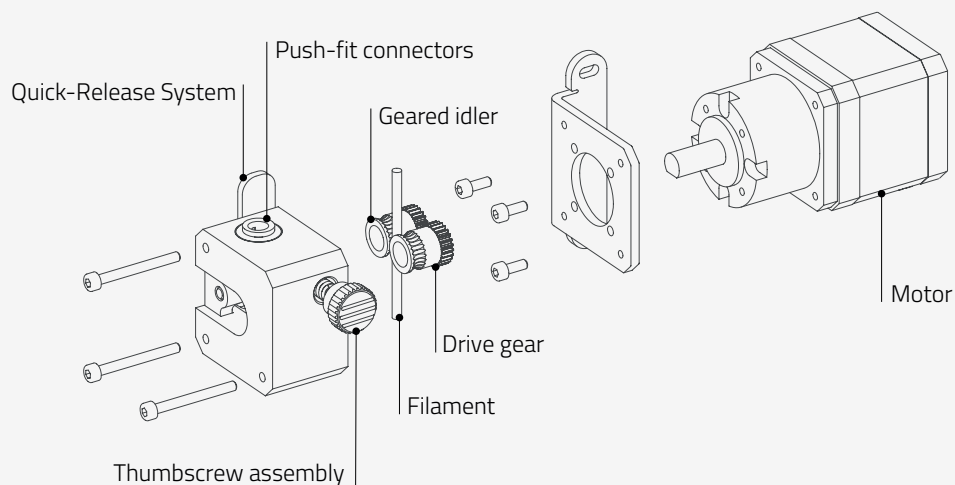


Figure 7. Parts of an extruder.

- *Drive gear*: gear driven by the motor through the relation imposed by the Gearing Ratio.

- *Geared idler*: this does not alter the speed of the output, it rotates in the opposite direction as the driver gear but at the same speed. It can be a gear or a cylinder.

- *Thumbscrew assembly*: allows the user to manually adjust the tension on the filament.

- *Quick-Release System*: assembly to disarm the gears and manually push the filaments.

- *Push-fit connectors*: clips that hold the PTFE tubes into the extruder.

⁴Parts for Bowden Extruder. Does not include Direct Drive Extruders.

Comparison. The importance of the Gear Ratio

The Gear Ratio of the Planetary Gearbox refers to the relation between the torque supplied by the motor and the motor rotational speed. In BCN3D motors, this Ratio is 5.18:1, which can be considered as balanced. It means the extruder is able to feed relative fast extrusion prints and also deal with fast retractions. This Gear Ratio and the grip offered by the Bondtech DualDrive technology increases the resolution of the system as the extruder will be able to supply more Pushing Force, allowing the printer to work with low layer heights. To completely analyze the performance of the extruders, some values of Pushing Force that they can output to the filament are compared.

Pushing Force [N]

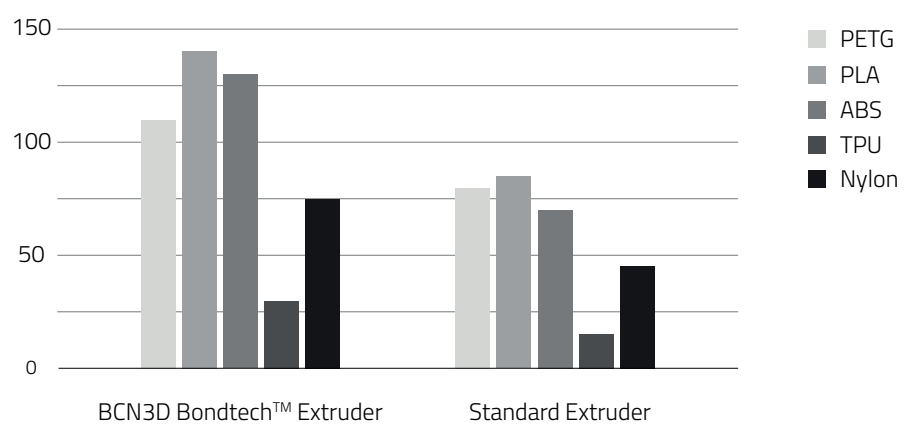


Figure 8. Pushing Force values for BCN3D Bondtech Extruder and Standard Extruder. Tested with PETG, PLA, ABS, TPU and Nylon.

Pushing Force for Bondtech™ Extruders is considerably higher than for any other standard extruder for all the studied materials. Additionally, even for flexible materials, which are known to be slippery and soft, extruders can supply a force that allows any printer to extrude them. In conclusion, they ensure that all filaments will be printable for complex and fast prints, apart from obtaining a high printing resolution.

Extruder versatility

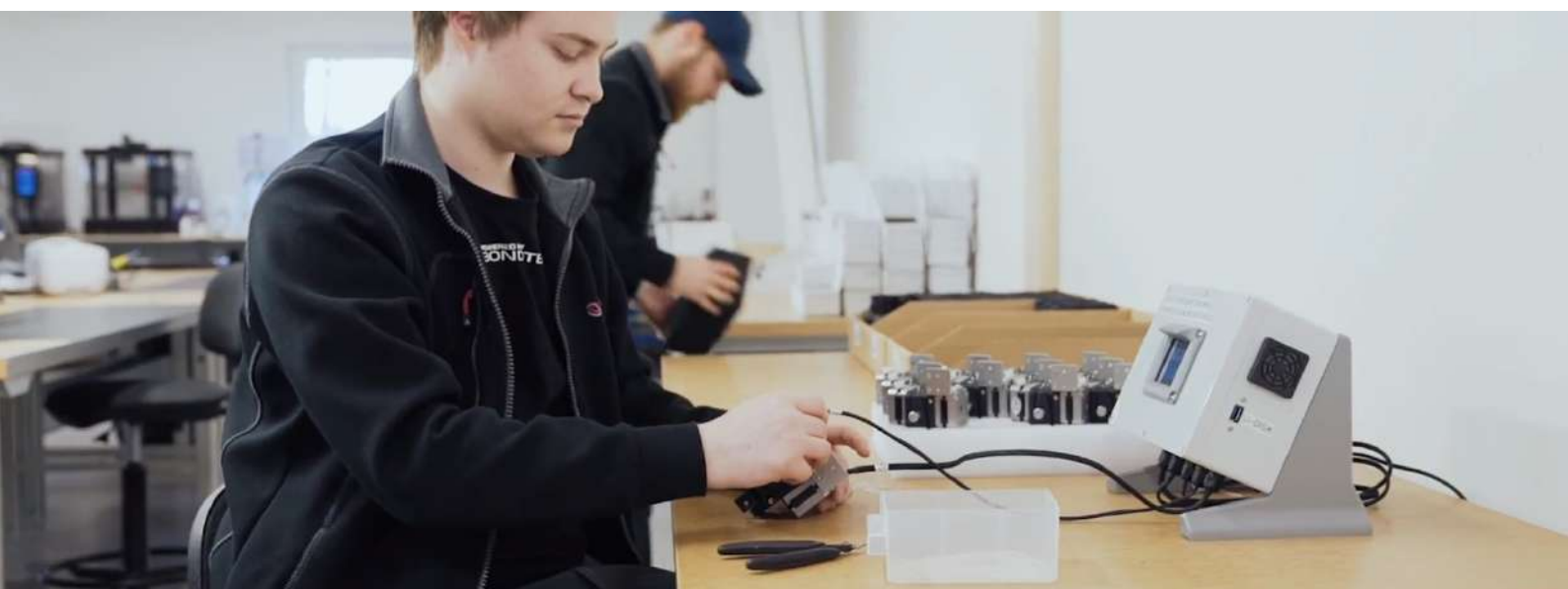
Apart from accepting a large variety of different materials, Bondtech™ extruders have been tested to ensure the performance of filament with diameter tolerances of $\pm 0.25\text{mm}$. The idler gear moves to ensure the filament passes through the extruder.

Bondtech™ know-how

Bondtech™ develops, designs and manufactures dual drive extruders that eliminate the risk of grinding, slipping, filament deformation and under extrusion. Using two counter-rotating drive gears, the Bondtech™ extruders grip and push the filament from both sides for a secure and stable filament feed. The result is a reliable, more precise and faster printing process. Delivers uninterrupted material flow without fear of failing in even the most demanding conditions.

Bondtech™ is a pioneer in extruders manufacturing and is a synonym of quality and reliability. Works with a huge volume of production and assembly is semi-automatic, as the majority of the competitors assemble everything manually. Each unit comes assembled, tested and verified for optimal performance.

Working with Bondtech™ has allowed BCN3D improve in terms of printing experience, as the extruders give users the markets highest performance, precision and reliability. BCN3D printers are now able to print in a more reliable way with all sorts of filaments, thanks to the DualDrive system.



04

Filament Runout Sensor

At BCN3D Technologies, thanks to continuous development, we set out to improve BCN3D printers reliability and offer a solution to the problems of running out of filament, through the Filament Runout Sensor (FRS).

It is a mechanical micro switch to detect filament presence, allowing to prevent from one of the most common and frustrating failure reasons. In case of running out of filament during a print job, the printer will automatically pause and warn the user to load new filament to resume the print, letting to save time and money.

The most important parts of an FRS are shown below:

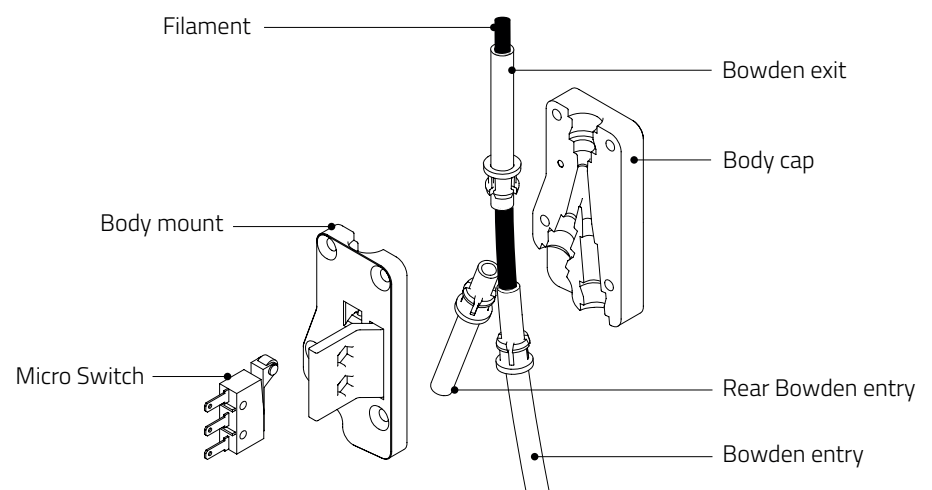
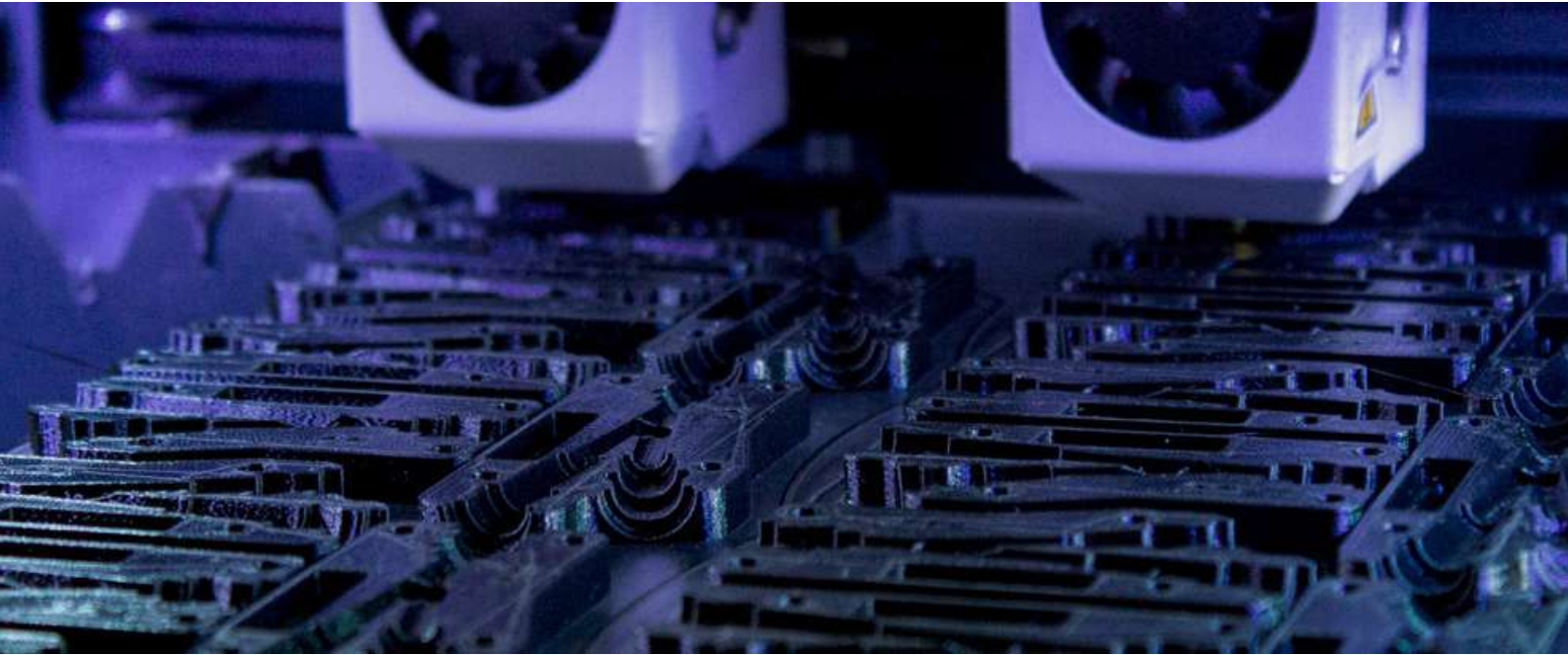


Figure 9. Parts of an FRS.

3D-printable body

A 3D-printable body for the FRS was a must, given the fact that several parts of BCN3D printers are manufactured in-house by other BCN3D printers, proving FFF technology as a perfect manufacturing technology for relatively low volumes. This alone would help BCN3D save on prototyping time and production costs down the line. Thanks to 3D printing, the number of design iterations could be higher, ending up with a refined design. Using Mirror and Duplication modes from BCN3D R19 printers, lead times were reduced considerably to fulfill the printers demand.



The material used to print the body is PET-G, mainly due to these facts:

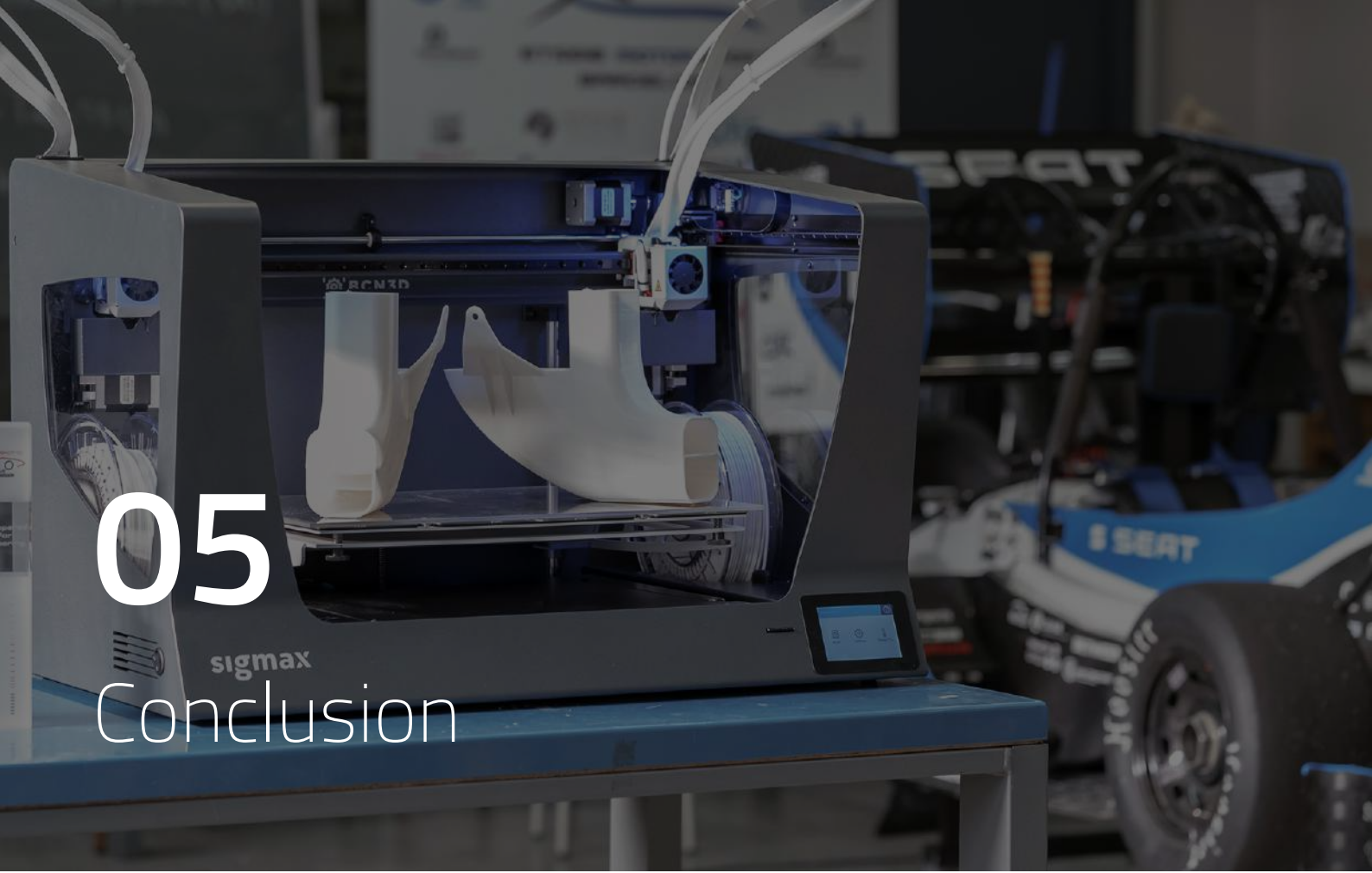
- Its high geometrical and dimensional accuracy.
- Good abrasion resistance.
- Withstand operating temperatures up to 70°C.

Sensor

The chosen sensor was a standard mechanical endstop with a roller actuator. It is capable to detect the lack of filament and pause the print job to load a new filament.

It has a tolerance of $\pm 0.25\text{mm}$, so deformations on the filament do not affect the performance of the mechanism.

The development of this new mechanism has allowed BCN3D to solve one of the most common troubles users found during their prints. The FRS goes in the same direction as the new hotends and extruders introduced before: set a new standard in reliability. It is also an example of how BCN3D takes advantage of its own technology to develop their products, during the design and production phases, and demonstrates that FFF 3D printing can be used to create end-use parts.



05

Conclusion

BCN3D has partnered together with top world manufacturers such as e3D™ and Bondtech™ in order to equip BCN3D printers with the top-grade components available nowadays in the 3D printing industry. These partnerships have allowed BCN3D to work closely with renowned companies in order to equip BCN3D printers with top-level features in terms of hotends and extrusion systems. The result can be found in the new Sigma R19 and Sigmamax R19, that feature a new extrusion system composed by extruders powered by Bondtech™ and hotends optimized by e3D™, apart from a new filament runout sensor to detect material presence.

Maximizing productivity with the most versatile 3D printers

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About BCN3D technologies

BCN3D Technologies is one of the leading manufacturers of desktop FFF 3D printers worldwide. Based in Barcelona, the activity of BCN3D began in 2012 and its aim is to help innovators and creatives to change the world, by offering them the best possible experience to materialize their unique ideas.

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