HEI MAKERS

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Technical creativity in 3D printing module

Co-funded by the Erasmus+ Programme of the European Union
2017-1-LT01-KA203-035231

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LESSON #3
3D PRINTING HARDWARE

Technical creativity in 3D printing module

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OUTLINE OF THE LESSON #3

- Topic 3.1. 3D printer key components – most important components of FDM/FFF 3D printer and their variations
- Topic 3.2 3D printer motion control and design principles – how an FDM/FFF 3D printer moves; variations of Cartesian and Delta printers
- Further learning
- Tasks for reflection

TOPIC 3.1 3D KEY COMPONENTS

- In this topic you will learn about basic components that most popular 3D printers are made of , how they function and how different choices of components affect your 3D printing results

- Expected learning outcomes: basic knowledge on most important 3D printer parts and their variations

Duration	1 academic hrs
Author / Lecturer	Rihards Rieka, RTU
Delivery methods	Individual / Teamwork / P2P
Evaluation methods	Test / Report / Feedback / Exam etc.

KEY COMPONENTS OF AN FDM/FFF 3D PRINTER

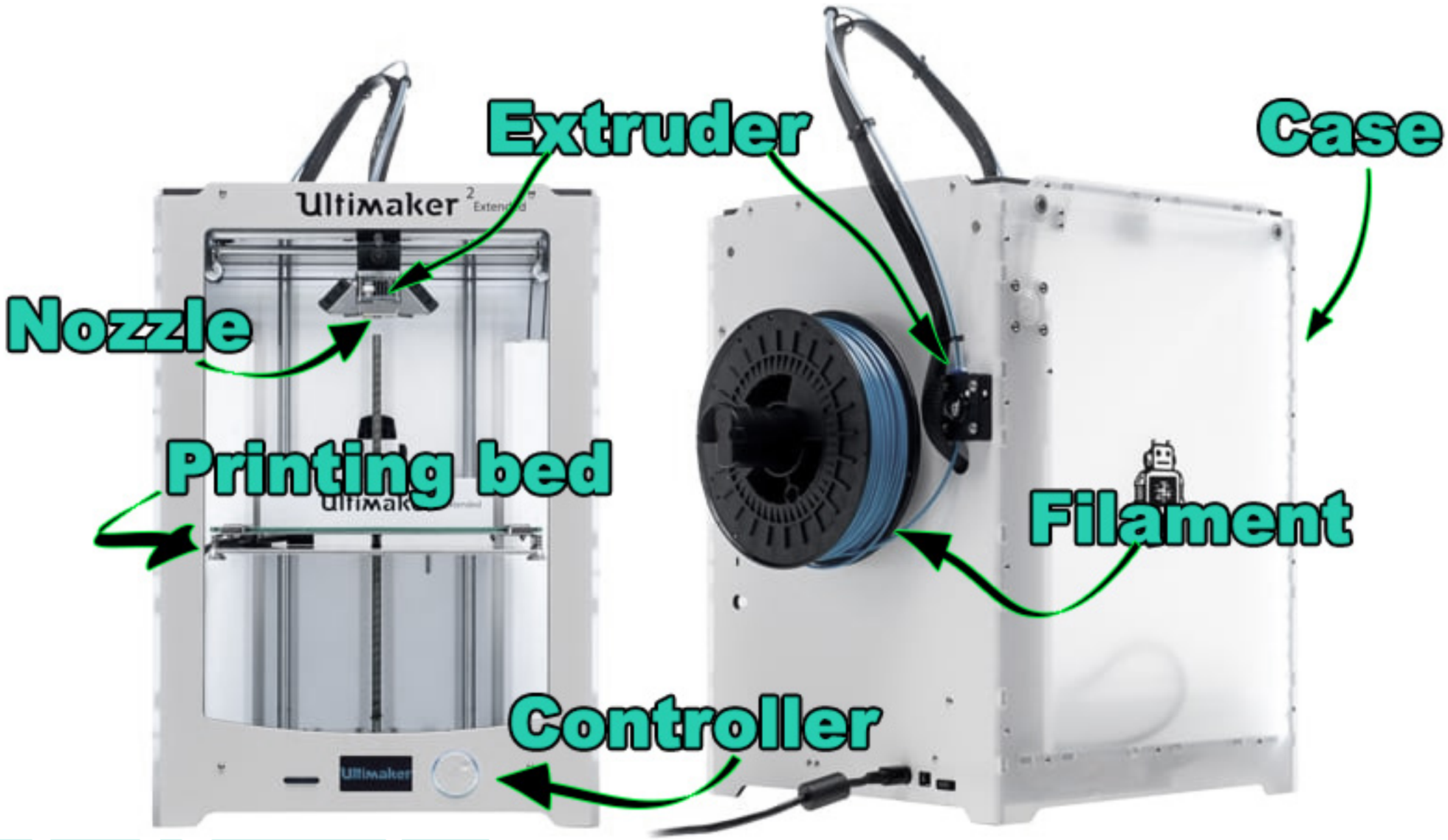


Figure 3.1.1. Key components. Source: RTU

EXTRUDERS

The extruder is a series of parts that together handle the moving and processing of plastic filament. Because it is one of the most important parts of the printer, it is often referred to as ‘’the core of the printer’’. It consists of 2 main parts – the cold end and the hot end. Those 2 parts then include a lot of smaller components and details.

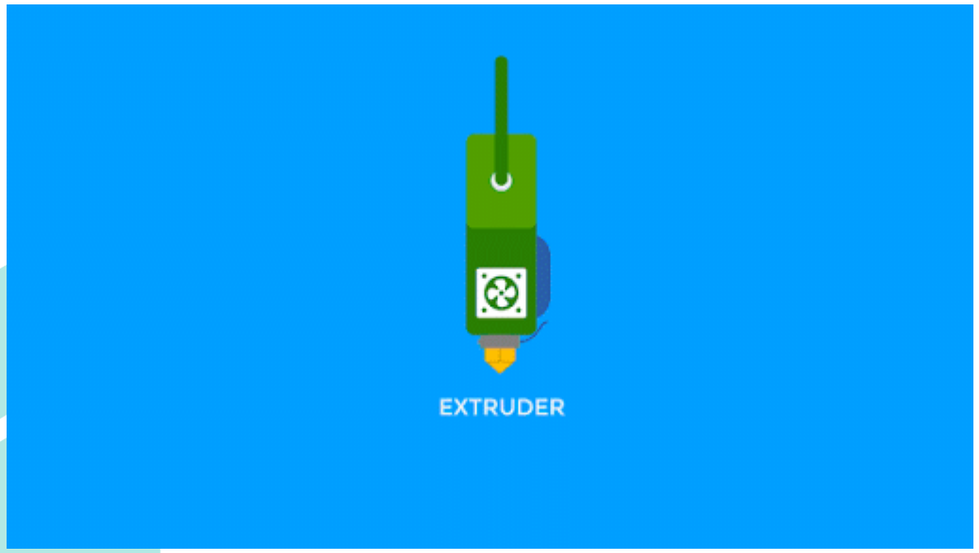


Figure 3.1.2 An extruder. Source: https://www.matterhackers.com/articles/anatomy-of-a-3d-printer [2019]

THE COLD END OF EXTRUDER

The cold end of extruder consists of:

- a motor that pushes the filament from the spool to the hot end
- Preferably a hobbed gear that is used to increase the torque

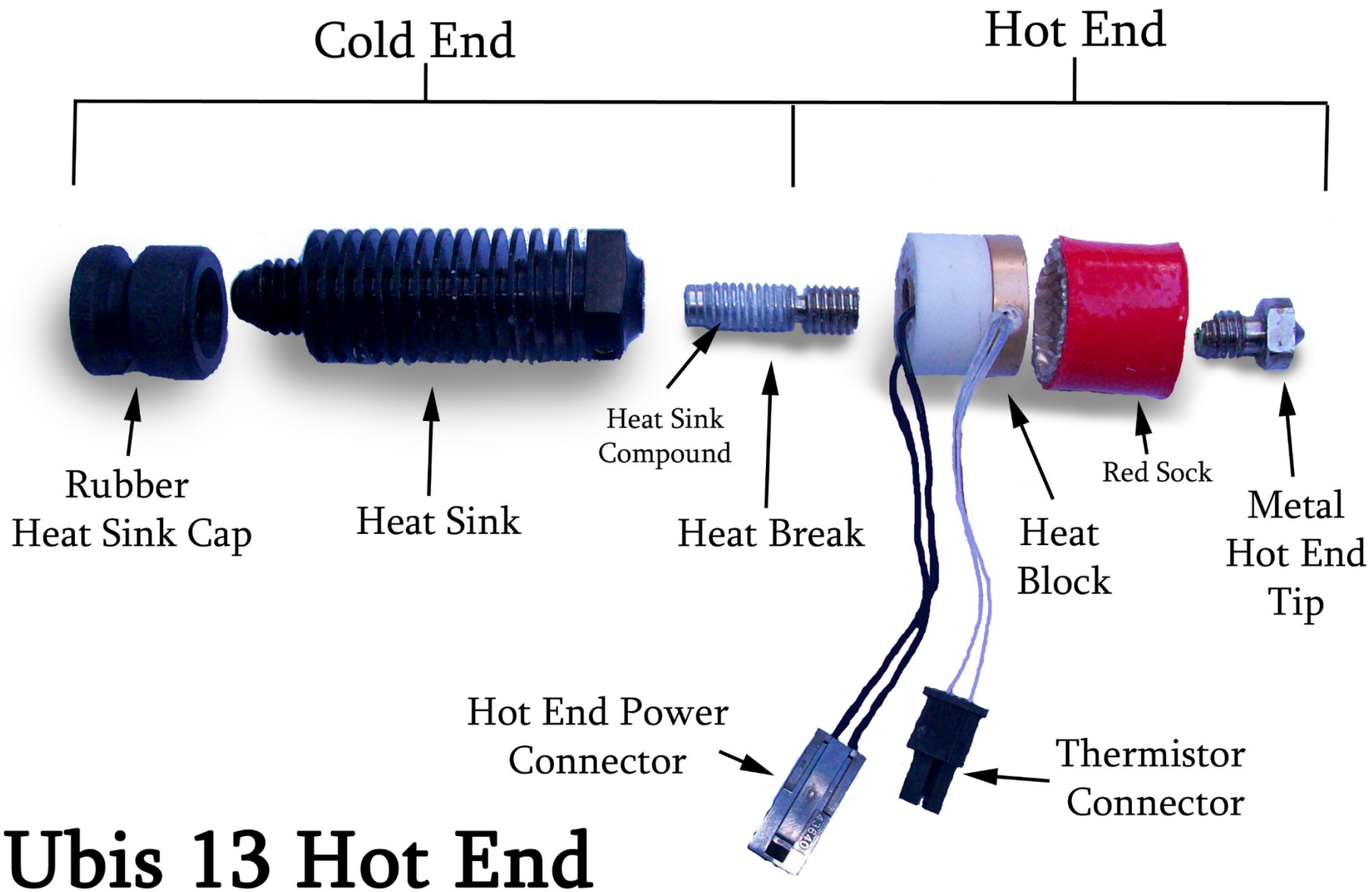
Between the cold end and the hot end sits a heatsink, so that filament doesn't get hot and clog up before reaching the heating block.

Figure 3.1.3. The hot end of an extruder. Source: https://all3dp.com/1/3d-printer-extruder-nozzle-guide/ [2019]

THE HOT END OF EXTRUDER

The hot end of extruder consists of:

- a heating block or cartridge that heats up the filament
- A thermistor or thermocouple which works as a temperature sensor for hot end
- A cooling fan that cools the filament as soon as it is deposited on the print bed, helping it hold its shape
- A nozzle which is located on the tip of the hot end (more information about nozzle in next slides)



Ubis 13 Hot End

Figure 3.1.4.Schematic of extruder on Ubis 13 extruder. Source: https://www.reddit.com/r/PrintrBot/comments/4srd8b/ubis_13_heat_sink_always_coming_loose_from_rubber/ [2019]

3 MAIN TYPES OF EXTRUDER CONFIGURATIONS

In 3D printers, there are mostly 3 types of extruder setup used :

- Bowden
- Direct drive
- Floating or flying

THE BOWDEN CONFIGURATION

3DP that have their extruders mounted to the frame are called Bowden. In Bowden setups there is a Teflon tube connecting the cold end (motors and gearing) to the hot end in the print head, directing the filament into it.

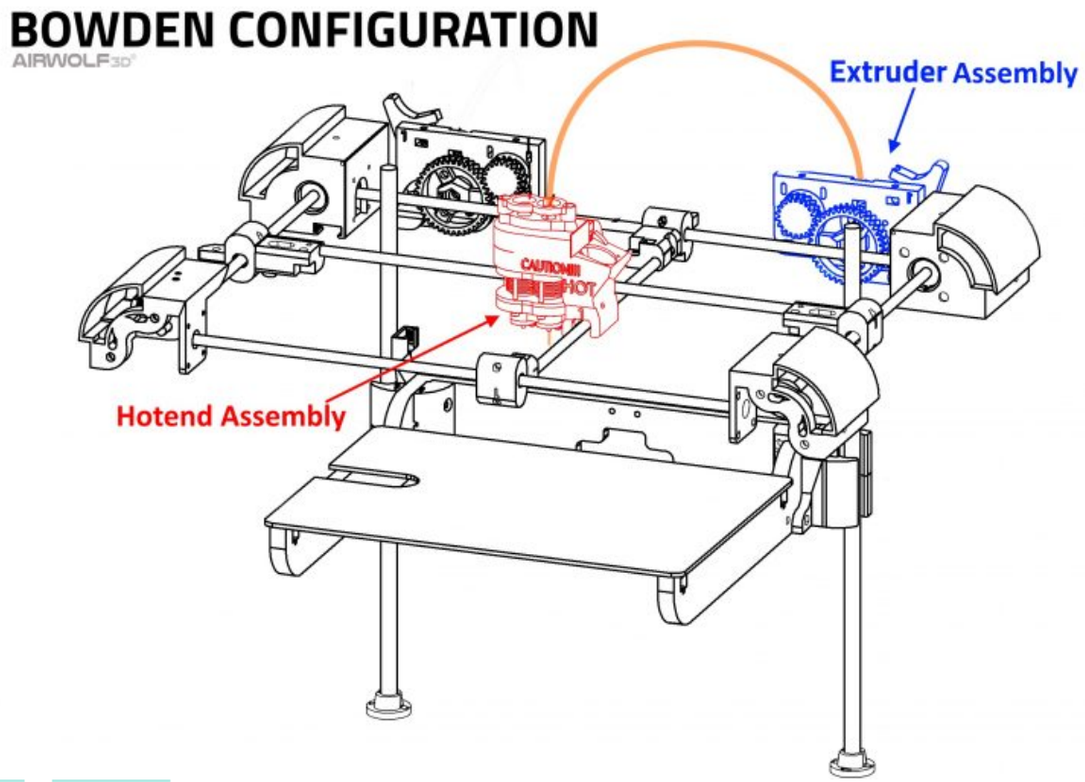


Figure 3.1.5.Bowden configuration. Source: https://airwolf3d.com/comparing-bowden-vs-direct-drive-3d-printer/ [2019]

The biggest strength of a Bowden-style setup is that it is able to move and print faster. That's because there is less mass on the hot end, as the motor is mounted to the frame. However, there is also a major drawback - homogeneity of material variance that can be printed at acceptable resolutions. More flexible materials require a lot more software tuning to work well because of the increased distance they have to travel from the drive to hot end.

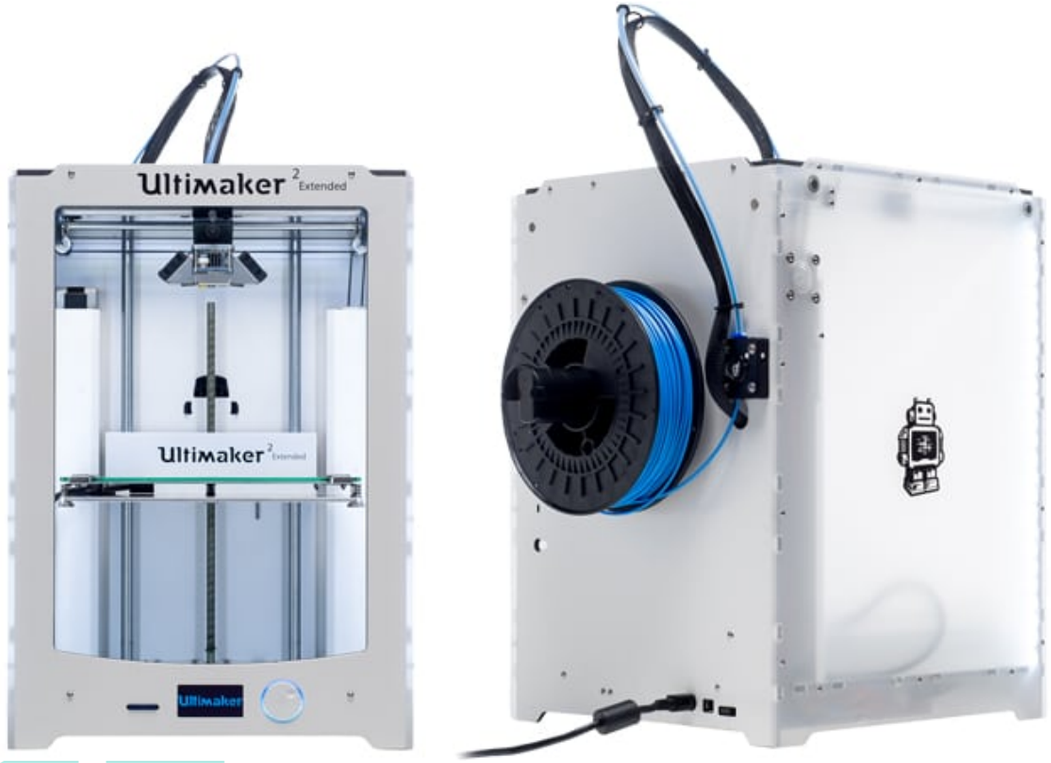


Figure 3.1.6.One of the most popular 3D printers for consumers – Ultimaker 2 , which uses an Bowder setup. Source: https://www.think3d.in/ultimaker-2-extended-review/ [2019]

DIRECT DRIVE CONFIGURATION

3DP that have their extruders mounted directly to the print head are called direct drive.

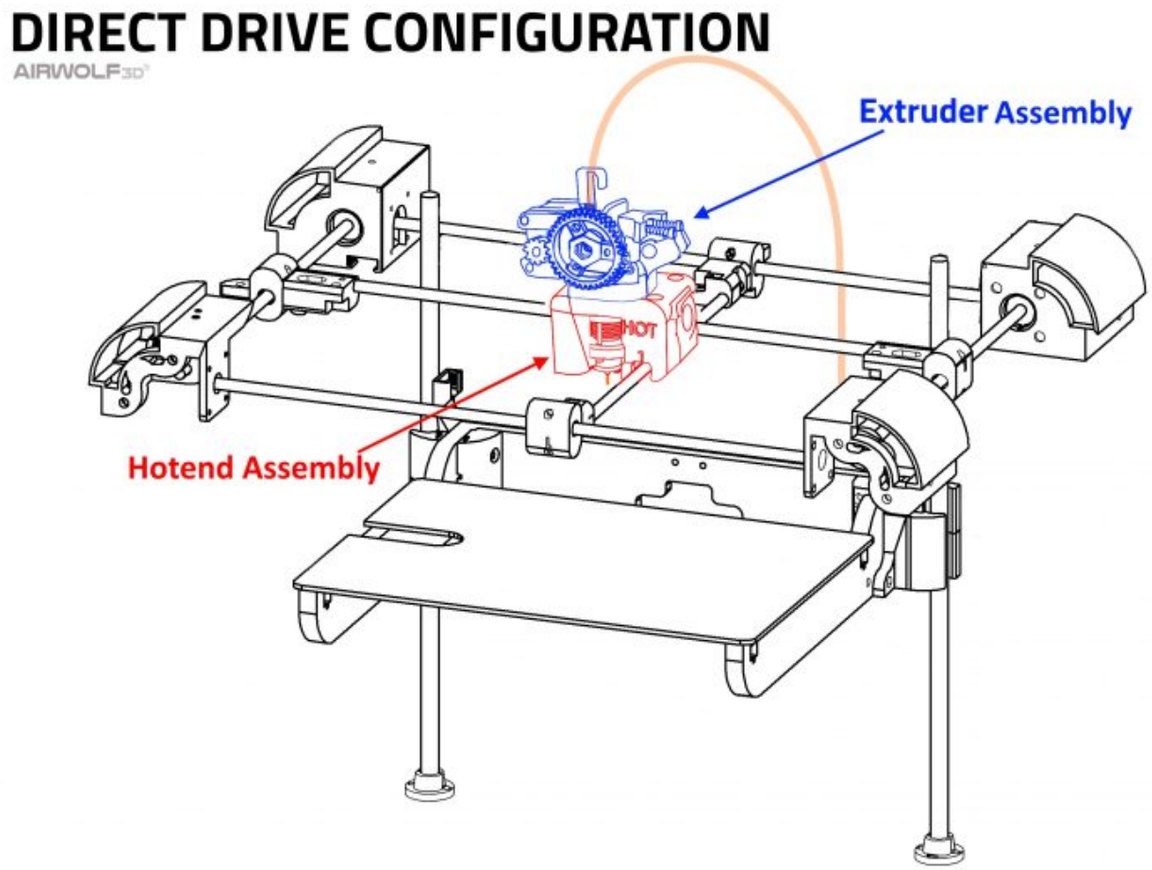


Figure 3.1.7.Direct drive configuration. Source: https://airwolf3d.com/comparing-bowden-vs-direct-drive-3d-printer/ [2019]

Direct drive configuration 3DP tend to be more stable because the motors are close to the hot end. Extrusion and retraction commands are more immediate which results in higher resolution prints.
Limitation with direct drive configuration is increased mass on the print head which causes more vibrations and backlash at higher speeds than Bowden setup. Furthermore, the speed is more limited with direct drive printers.

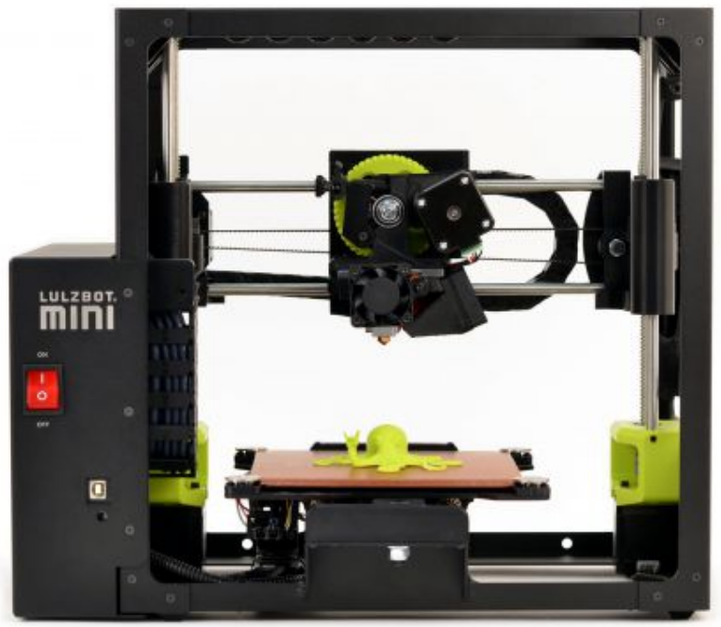


Figure 3.1.8.One of the most popular beginer 3D printers – LulzBot mini, which uses an direct drive setup. Source: https://cdn.mos.cms.futurecdn.net/35fThqZTEDx9ysGh9fnrnF-650-80.jpg [2019]

FLOATING OR FLYING CONFIGURATION

Floating or flying configuration extruders are quite rare comparing to other 2 types of extruders. They are mostly used on Delta 3DP. The cold end with motor is ‘’hanged’’ in between the spool and the hot end of the extruder. This setup comes somewhere in between of other 2 types when talking about pros and cons. There is reduced mass on the print head, but also the distance is shorter than with direct drive. That being said, this setup adds a bit of complexity to the overall setup of the printer.

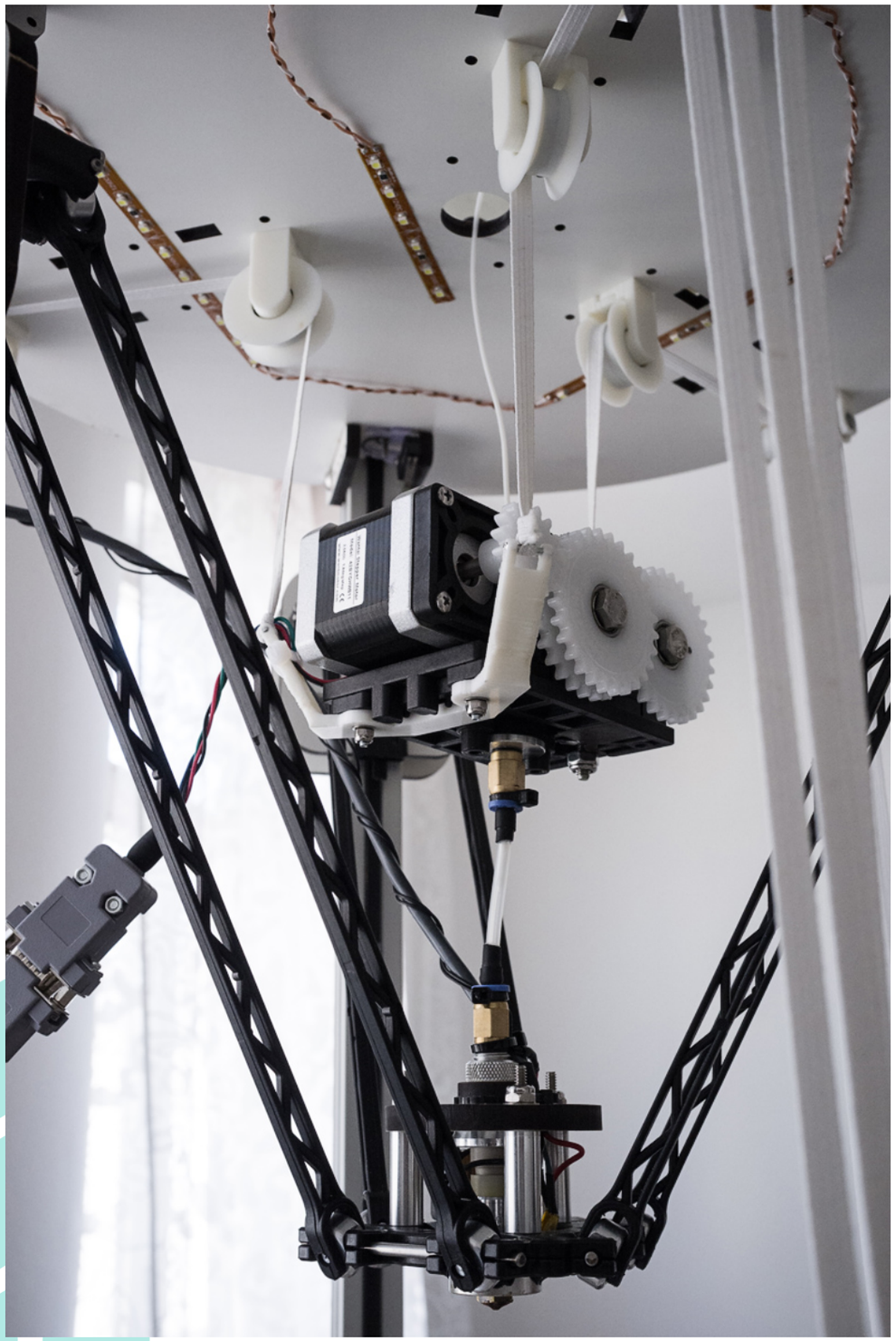


Figure 3.1.9.An example of floating setup extruder on an Delta printer. Source: http://abload.de/img/dscf3168j6o4t.jpg [2019]

A SUBCATEGORY OF EXTRUDERS

Within the previously mentioned categories of extruders, another subcategory should be mentioned. This category applies to the cold end of the extruders. There are 2 types of motors and gearing in cold end:

- Direct extruders
- Geared extruders

DIRECT EXTRUDERS

With direct extruders, there is a gear on the motor shaft of the stepper motor which is directly connected with the filament. This setup works with 1,75mm filament fine, but may struggle with 3mm filament because the lack of the torque supplied by the gear on the motor shaft.

Figure 3.1.10.Direct extruder. Source: https://www.matterhackers.com/articles/extruders-101:-a-crash-course-on-an-essential-component-of-your-3d-printer [2019]

GEARED EXTRUDERS

With geared extruders, there is a gear on the motor shaft of the stepper motor which is then connected to another gear that interacts with the filament. This setup works with both 1,75mm and 3mm filament well because the gearing supplies more torque to push the 3mm filament easier.

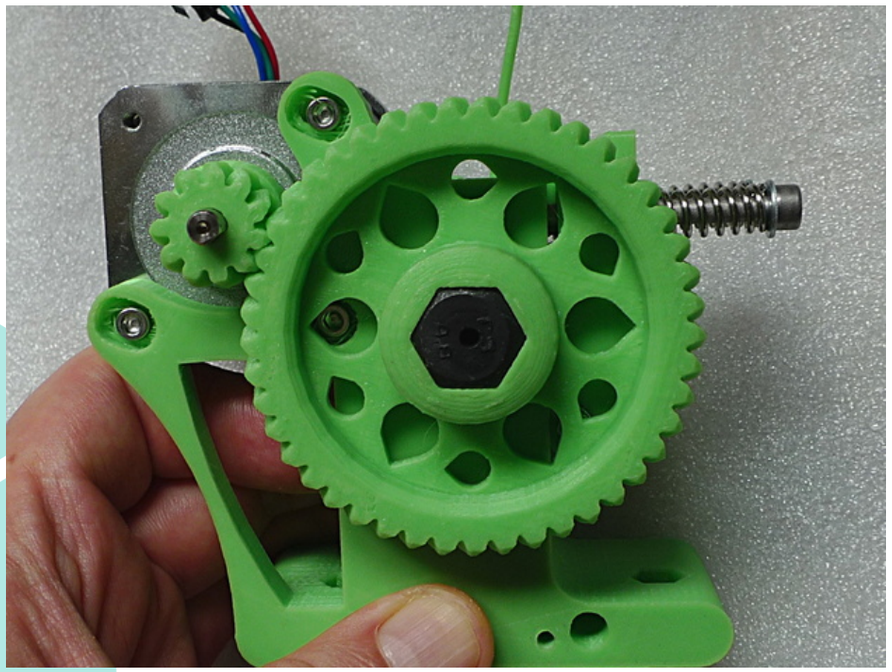


Figure 3.1.11.Geared extruder which is also 3D printed. Source: https://www.thingiverse.com/thing:961630 [2019]

CHOOSING AN EXTRUDER

When choosing a printer with already attached extruder or building your DIY setup, things to consider about extruders:

- Complexity of the extruder (for ease of maintenance)
- Material that will be used (more/less flexible, size)
- Printing speed
- Printing quality

CASE STUDY – PRINTERS AND THEIR EXTRUDER TYPES

In this case study we can look at 2 different printers and analyze their extruder types.

Ultimaker 2+

As we can see, the cold end is mounted on the side of the frame. Also, the motor is connected directly to the filament that is moving through the cold part. This means that this printer has a direct Bowden extruder.

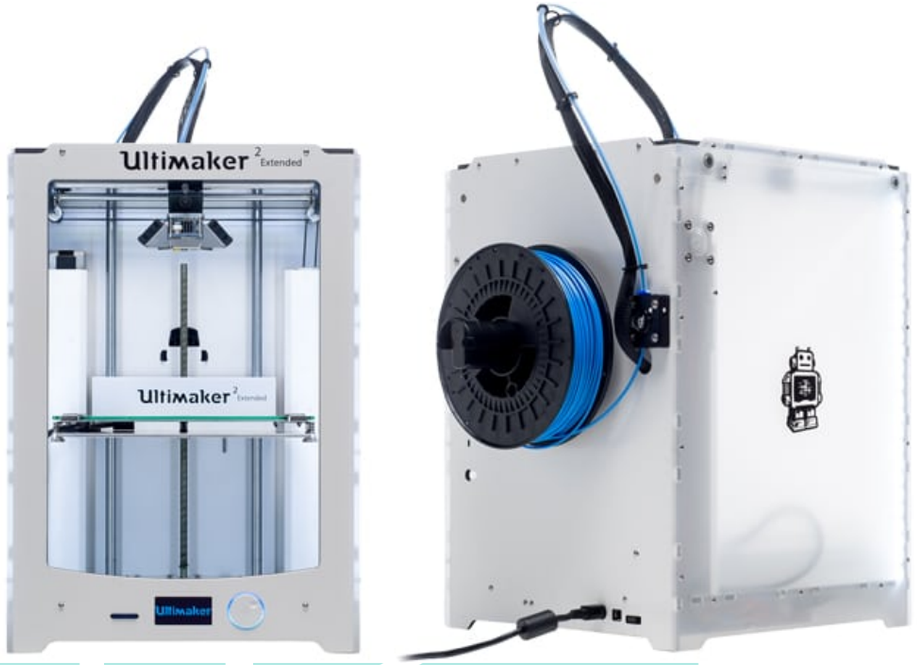


Figure 3.1.12.One of the most popular 3D printers for consumers – Ultimaker 2 , which uses an Bowder setup. Source: https://www.think3d.in/ultimaker-2-extended-review/ [2019]

Figure 3.1.13.The cold end of the extruder on the Ultimaker 2+. Source: https://www.think3d.in/ultimaker-2-extended-review/ [2019]

Lulzbot Taz 6
Here we can see that the print head is quite big and includes a very easily visible cog – that means that whole extruder is on the print head. Also, when taking a closer look on the extruder itself, we can see 2 different cogs, as the smaller one is connected to the motor. That means that Lulzbot Taz has a geared direct drive extruder.

Figure 3.1.14.LulzBot Taz. Source: https://www.3dhubs.com/3d-printers/lulzbot-taz-6 [2019]

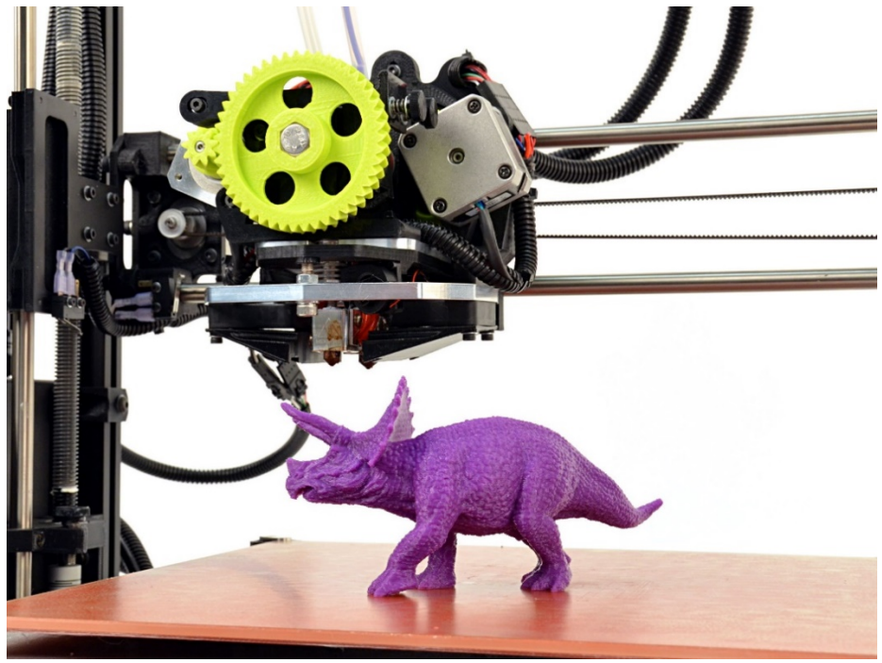


Figure 3.1.15.The cold end of the extruder on the LulzBot TAZ. Source: https://www.think3d.in/ultimaker-2-extended-review/ [2019]

NOZZLES

The Nozzle is the tip of the hot end where the plastics comes out. As it is the exit point of the extruder, it is without a doubt very important. Most important parameter of the nozzle is the size, but the material is also important. It is recommended to have at least few nozzles so you can swap them out if some get clogged with material, or you need to change the working flow or quality of your print.

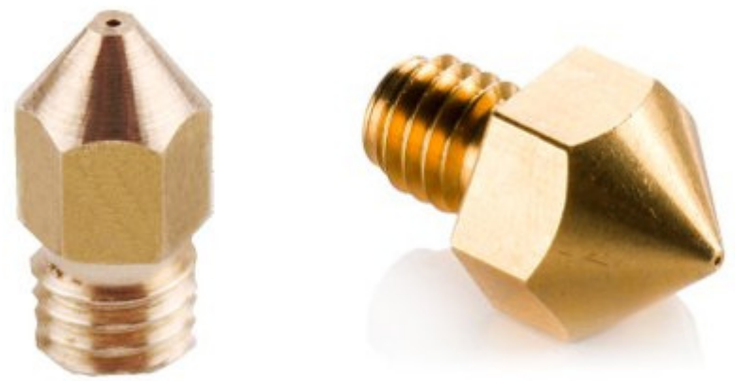


Figure 3.1.16. A nozzle. Source: http://www.tridimake.com/2016/06/3d-printing-nozzles-characteristics.html [2019]

NOZZLE SIZE

The nozzle size is really important. It usually varies from 0.25mm to 0.75mm. The most common size is 0.4mm, which gives a good balance between speed and print quality.

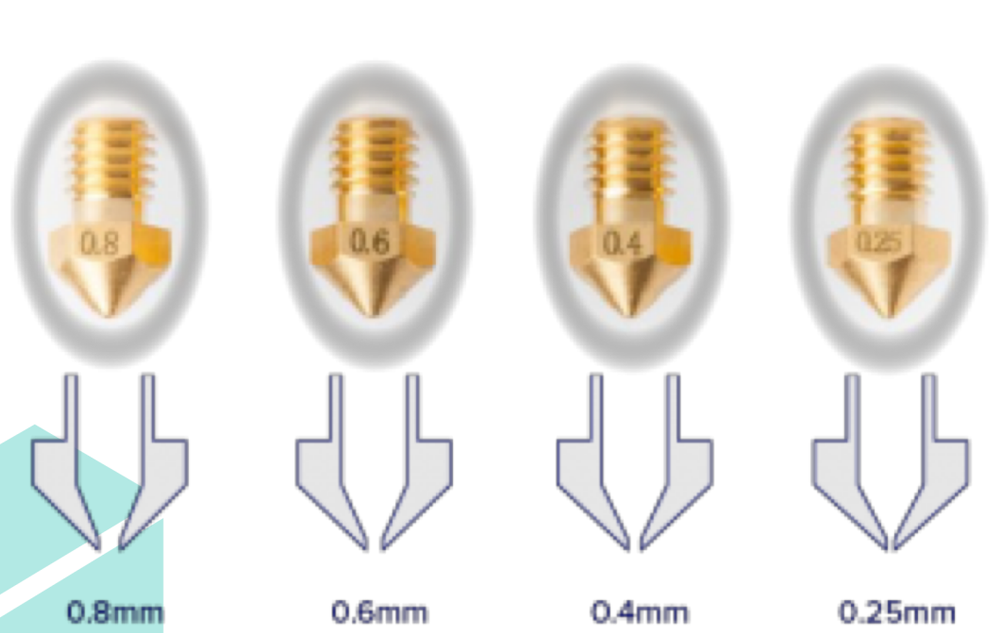


Figure 3.1.17. Nozzle sizes. Source: http://my3dconcepts.com/explore/main-components-of-desktop-3d-printers/ [2019]

Bigger nozzle, for example 0,8mm, will make the printing faster because the strings of the material will be thicker and there will be less layers. Bigger nozzle will also allow the first layer to stick to printing bed better. Finally, there is also increased printing reliability because of the faster printing time and less under-extrusion.

Smaller nozzle, in exchange for slower printing speed, will give smoother finish because of the thinner extruded lines and smaller layer height. The print should also be more accurate and more detailed.

NOZZLE MATERIALS

As the nozzle size will make a big impact on your overall print, the material of the nozzle also plays a big role in printing work flow.

Brass nozzles are the most popular in 3D printers. Brass is very thermoconductive, which means it will transfer heat from the heating block to the filament very efficiently. It is also relatively cheap to make. On the other hand, brass is also quite soft metal, which means it will wear out quicker from using adhesive materials or hitting the printing bed.

Figure 3.1.18. Nozzle materials. Source: https://www.matterhackers.com/news/3d-printer-nozzle-comparison-guide [2019]

Stainless steal is also quite popular and more wear resistant than brass. Another good property of stainless steal nozzles is that it will stay very clean of material on the tip, leading to cleaner look and less maintenance needed.
Hardened steel nozzles are next in term of updates, and if treated right, can be very wear resistant. It also should give no problems with printing abrasive materials like NylonX.
Specialty materials are also used when making nozzles. One of the best solutions is brass nozzle with Ruby tip, which is used to make harder nozzles that can stand up to constant abrasion. These are pretty much indestructible, but also cost a lot more than other materials.
There are a lot more options when it comes to nozzle material, but most of them are made for special uses and not that popular for most of the users.

PRINTING BEDS

The printing bed or build surface is the surface that your objects are printed on to.
Printing bed will most likely consist of a heating element, a sheet of glass and some kind of surface material on top of the glass to help the plastic stick to it.

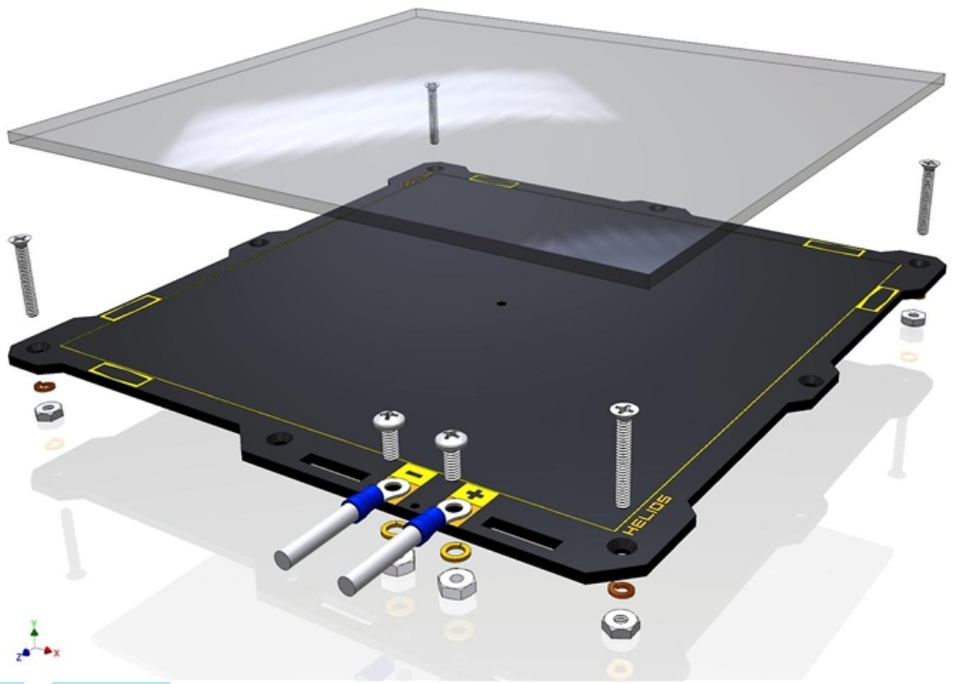


Figure 3.1.19. A printing bed. Source: https://pinshape.com/blog/how-do-3d-printers-work/ [2019]

HEATED/NON HEATED BEDS

In most cases, print beds are heated. Due to thermal contraction, the plastic may shrink as it cools, which causes the printing object to wrap. Heating the bed will prevent the print from wrapping by keeping the bottom of the print warm.

HEATED PRINTING BED FAILURE

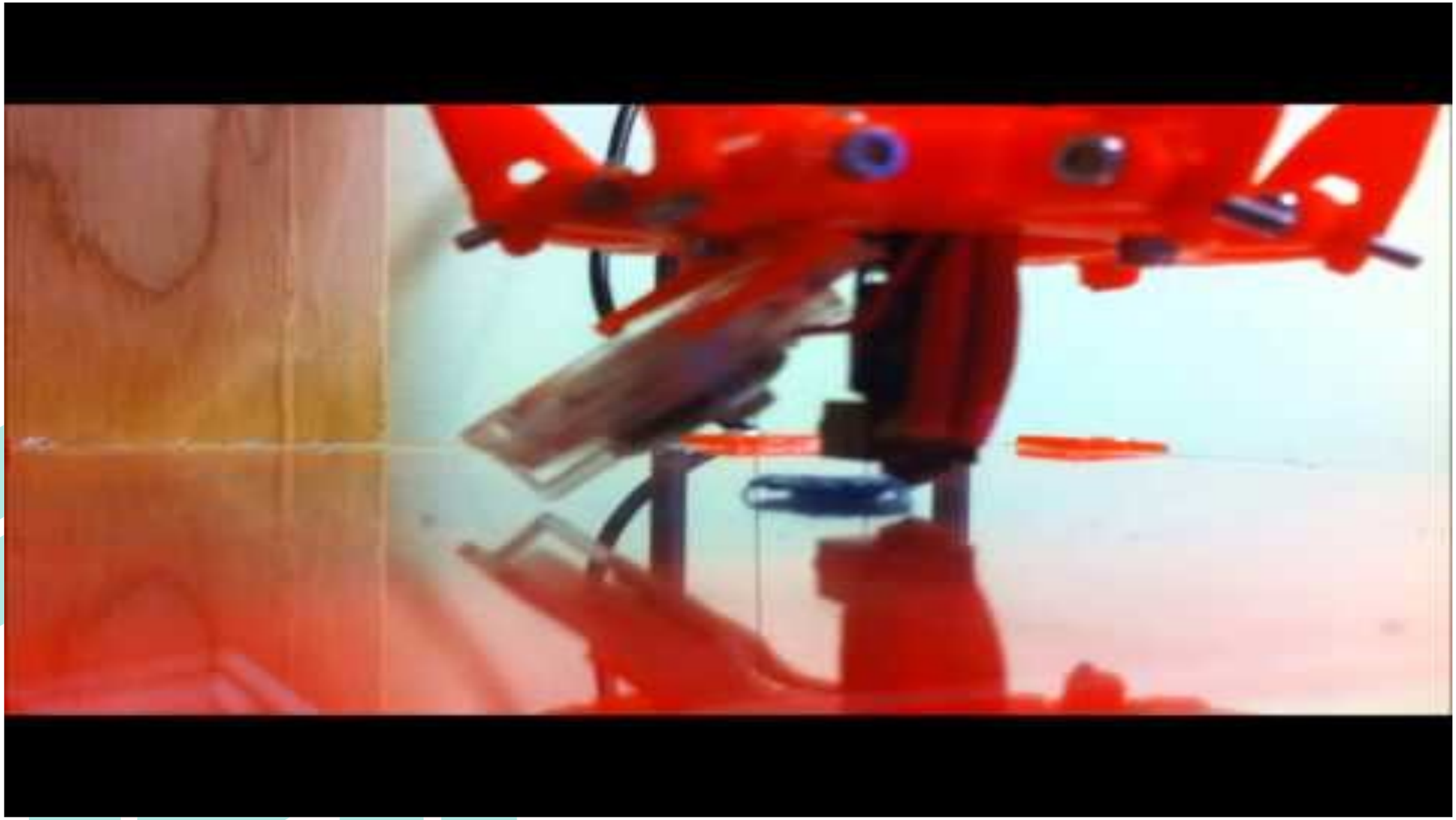


Figure 3.1.20. Why the bed needs to be heated. Source: https://www.youtube.com/watch?time_continue=42&v=Z0YYeTzCZEw

MATERIALS ON BED SURFACE

There are many different ways about preparing your printing bed surface for your print. For the best result you want your print to stick well to the surface , however you have to get it off without damaging it after the printing is completed.
A very popular way to solve this problem is adding a adhesive surface or material on top of the heated glass plate. Here are some examples.

- A cheap way that works well ABS is applying a small amount of hairspray on the printing bed, or going over the surface with a PVA glue stick for PLA and some other materials

- Some printers use a plastic sheet called PEI (polyetherimide), which sticks very well to 3D printed parts when heated up but releases when it cools down

- There are special tapes, e.g. Kapton Tape that you put on the glass surface, which acts as adhesive when printing ABS

You can also mix those options together, e.g. Add a bit of PVA glue stick to PEI sheet to ensure your 3D print will stick but not weld completely to the bed.

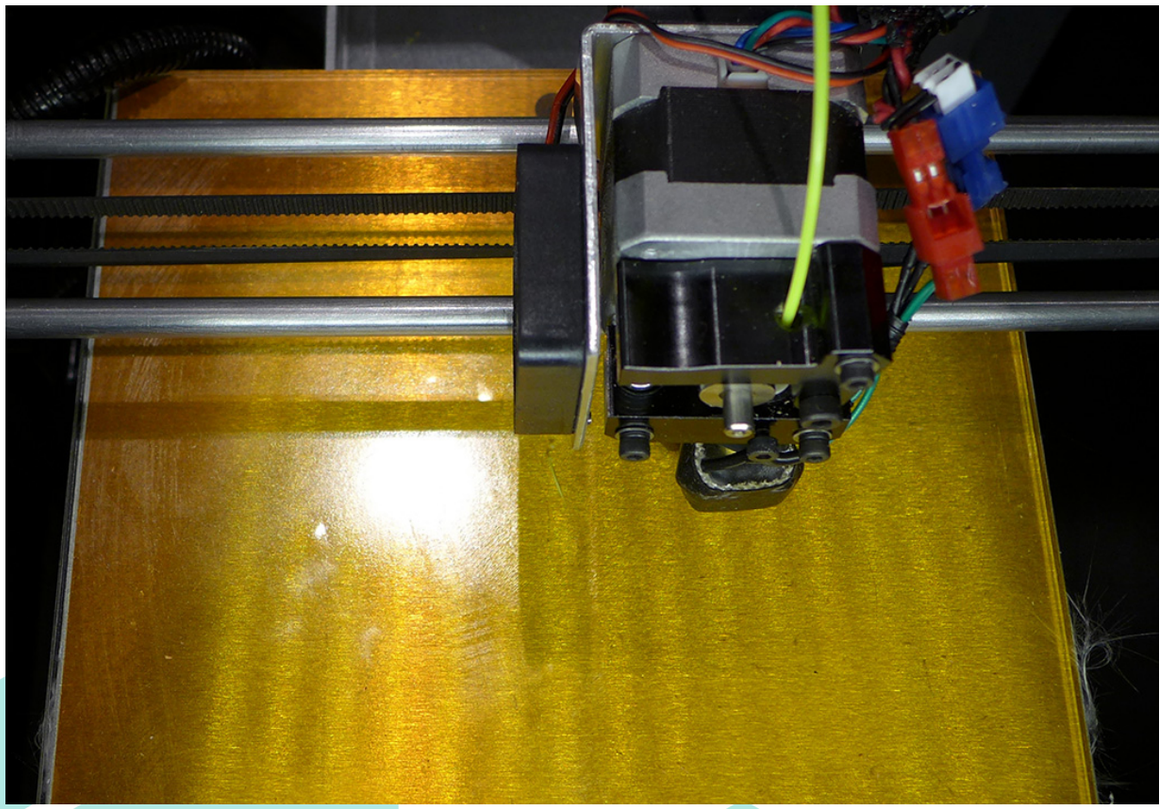


Figure 3.1.21. Kapton tape. Source: https://www.tested.com/tech/487154-my-favorite-things-2014-3d-printing-essentials-electronics-lego/

Figure 3.1.22. PEI sheet. Source: https://www.matterhackers.com/store/printer-kits/lulzbot-taz-4-3d-printer

STEPPER MOTORS

To move the extruder and the printing bed, stepper motors are used. They are special DC motors that make full rotation in increments of steps. That makes them more precise that tradition DC motor.

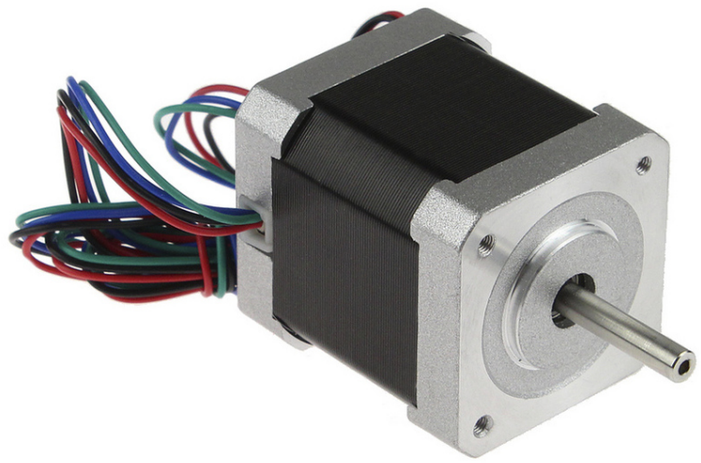


Figure 3.1.23. A stepper motor. Source: https://www.inventables.com/technologies/stepper-motor-nema-17 [2019]

Stepper motors work in increments or steps. Most of the steppers will have 200 steps per one full revolution, although now there are stepper motors that have even 400 steps per revolution.

By balancing the power fed to each coil, the driver is also able to divide steps up into further increments. This is called micro stepping and allows more precise control over the motor than is normally possible.
The quality of the motor can make a big difference in the accuracy of a print.

To control these motors, a special driver is used. This driver is then located on the 3D printer controller.

CONTROLLERS AND POWER SUPPLIES

Controller or the motherboard is what controls all parameters of printing work flow. It takes the commands from the G-Code, does all the mathematics and executes them in form of printing.
The motherboard consists of 2 main parts – a microcontroller together with all the sensors and communication, and the drivers that control the motors.

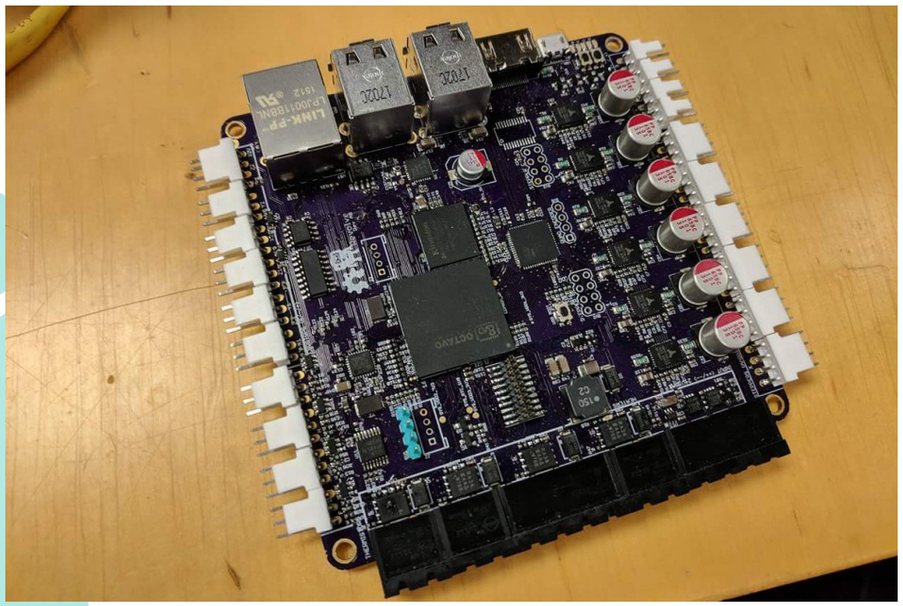


Figure 3.1.24. A printing bed. Source: https://all3dp.com/2/5-fantastic-3d-printer-controller-boards/ [2019]

SOME PARAMETERS OF CONTROLLERS

Controllers vary a lot between 3D printers. Some manufacturers make controllers specific for their printers, which means there isn't much room for improvements on changes. Others, however, make their controllers more open-source, where you can add different motors, sensors, extruders etc. Some of the many parameters that differ between controllers:

- Processors – 8/16/32bit – affect the speed of the controller
- How many extruders they support
- How many motors they support
- Interface – LCD, touchscreen etc..
- Communication – are parameters and g-code uploaded from a computer via USB, ethernet connection, SD card etc..
- Do they have free ports for other sensors, communication etc..
- Firmware

SOME PARAMETERS OF STEPPER DRIVERS

Stepper drivers are what control the stepper motors that move the extruder and printing bed. Some of the parameters:

- Soldered in or interchangeable
- Micro step count
- Pinout type
- Protocol
- Torque provided

PARAMETERS OF 3D PRINTER POWER SUPPLY

The power supply is what provides power to your 3D printer so it can work. These power supplies are very similar to the ones found on computers. Some machines run 12 volt systems, while others run 24 volt systems. One of the most important parameters of a printer is its power efficiency. It is good to know how much power it will take to use so you don’t end up with huge electricity bills.

Figure 3.1.25. A printing bed. Source: https://www.robotshop.com/en/afinibot-a5-3d-printer-power-supply.html [2019]

FURTHER LEARNING

3D printer setup depending on material – printing bed material, temperatures etc..
https://www.matterhackers.com/3d-printer-filament-compare

3D printer Troubleshooting – large material that provides information about most problems that you could come up to when 3D printing
https://all3dp.com/1/common-3d-printing-problems-troubleshooting-3d-printer-issues/

TOPIC 3.2 3D PRINTER MOTION CONTROL AND DESIGN PRINCIPLES

- In this topic you will learn about motion control side of 3D printer design and different types of 3D printer designs
- Expected learning outcomes: basic knowledge on different motion style printers and their working principles

Duration	1 academic hrs
Author / Lecturer	Rihards Rieka, RTU
Delivery methods	Individual / Teamwork / P2P
Evaluation methods	Test / Report / Feedback / Exam etc.

3D PRINTER MOTION CONTROL

Whole 3D printer is designed and built around one main goal – to be able to move the extruder or printhead around the printing bed to lay down material, that will later form the desired object. The extruder moves around in 3 axis as shown in picture below.

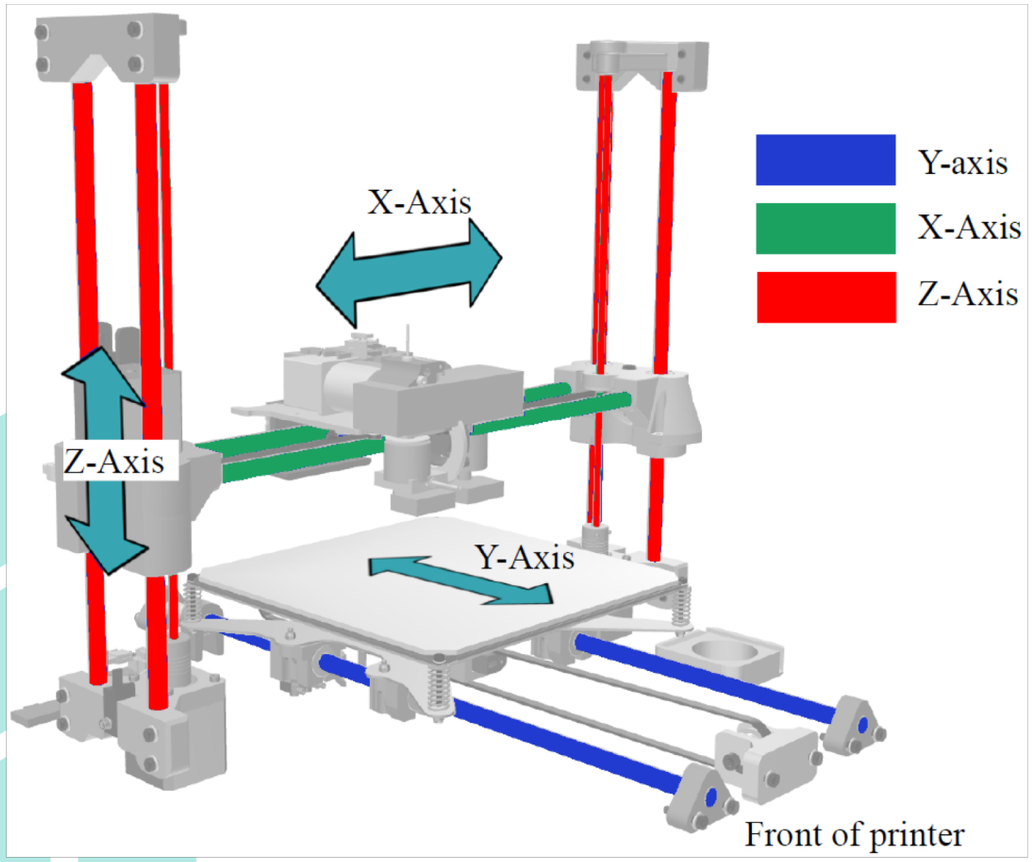


Figure 3.2.1. Axis. Source: https://revolution3dprinters.zendesk.com/hc/en-us/articles/225108188-Jogging-and-or-Axis-Movement-Control [2019]

MAIN DESIGNS

There are many ways how to move extruder around building area effectively. These design principles are formed into two main 3D motion control categories:

- Cartesian
- Delta

However, industry of 3D printers is developing fast, and there are whole new types of 3D printers being made. One example which will be shown is a Polar 3D printer

CARTESIAN DESIGN

Cartesian printers have one or two motors along each of the X,Y and Z axes. Build area – whole area where a 3D print can be made – is typically a rectangle. Printers themselves are mostly rectangular shape as well. This type of 3D printers is most popular along hobbyists, as well as manufacturers.

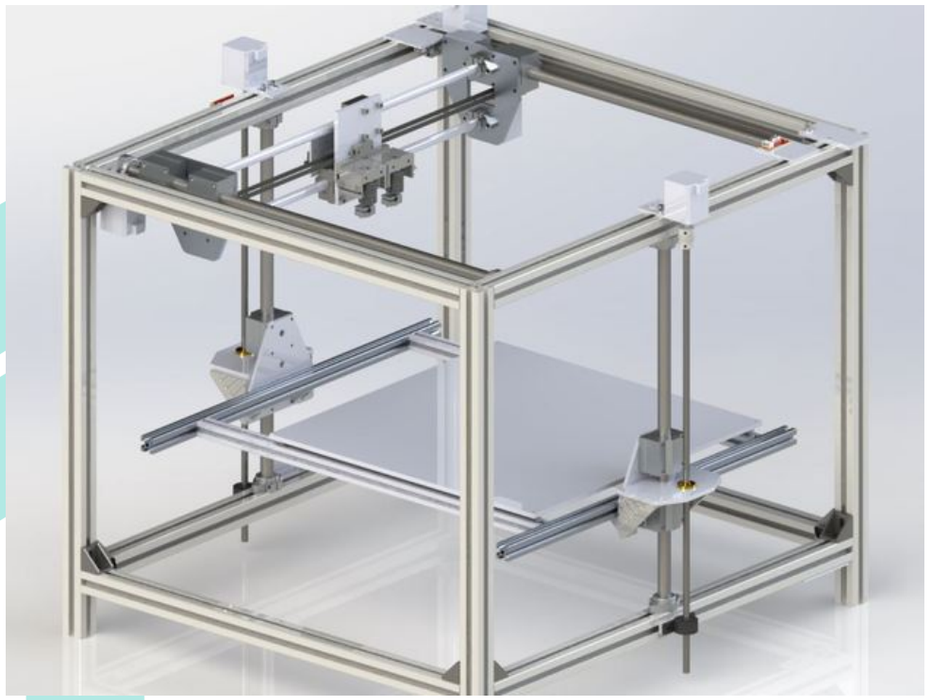


Figure 3.2.2. Cartesian 3D printer. Source: https://www.thingiverse.com/thing:1751332 [2019]

MOTION DRIVE FOR CARTESIAN PRINTERS

There are two main ways how Cartesian 3D printers are driven. Extruders are mostly Belt driven, where stepper motors with gearing is used to move belts around. Printing bed, when moved along Z axis, is using a long threaded rod that rotates, forcing locking nuts move up and down. Different printers may use different drive systems on each axis.

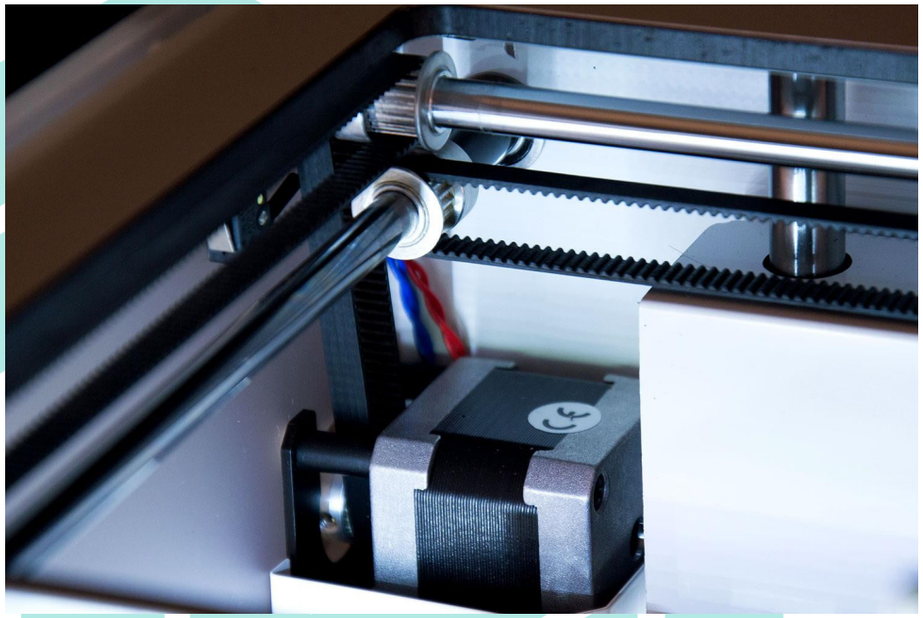


Figure 3.2.3. Belt drive. Source: https://www.digitaltrends.com/3d-printer-reviews/ultimaker-2-review/ [2019]

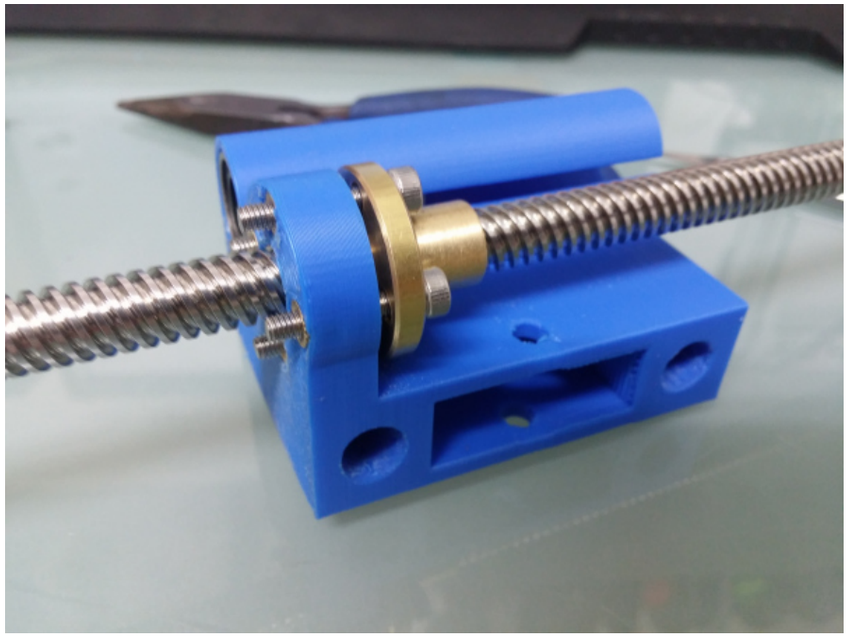


Figure 3.2.4. Threaded rod. Source: https://hackaday.com/2015/11/26/upgrading-a-3d-printer-with-a-leadscrew/ [2019]

CARTESIAN DESIGN CONFIGURATIONS

Cartesian printers have many different configurations depending on how each axis is moved. We will take a look on most popular types of Cartesian printers :

- XY Head
- XZ Head
- Core XY

XY HEAD

In XY HEAD configuration the extruder head moves over the X and Y axis while the printing bed moves over Z axis. Actually, the first 3D printer was made with this configuration. This configuration is very precise, but the bed needs to be lightweight to print efficiently. Popular XY Head printers include Ultimaker 2/3, Makerbot Replicator and many others.

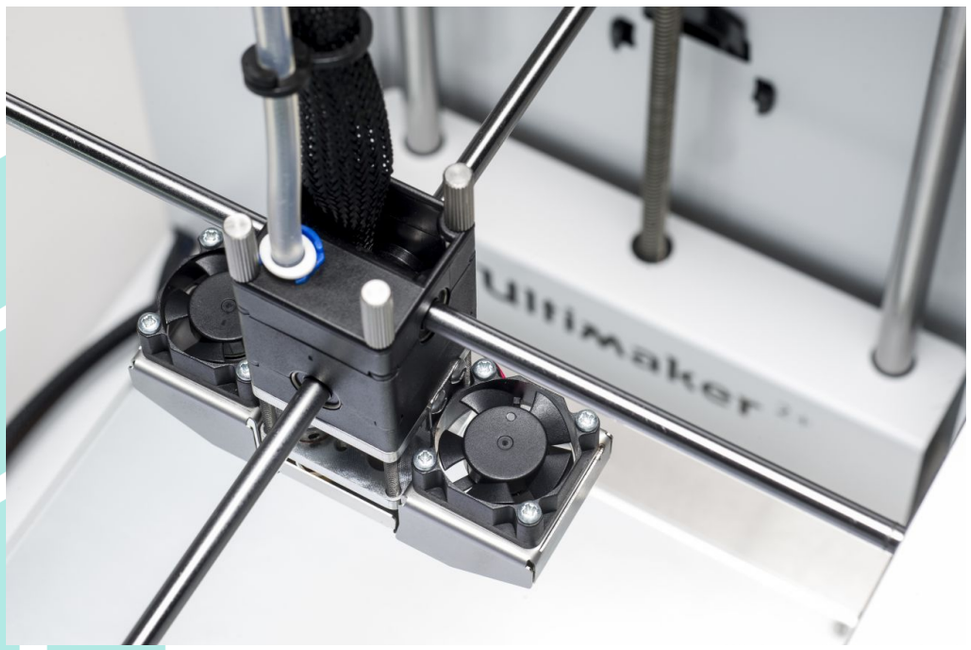


Figure 3.2.6. XY Head printer. Source: https://ultimaker.com/en/resources/19487-x-or-y-switch-broken [2019]

XZ HEAD

In XZ HEAD configuration the extruder moves over the X and Z axis but the printing bed moves over the Y axis. Benefit of this configuration may be less wobble over Z axis resulting a better layer quality, but build space is also limited due to the moving of the bed. Popular XZ printers are Prusa Mendel, Metalbot 3 etc..

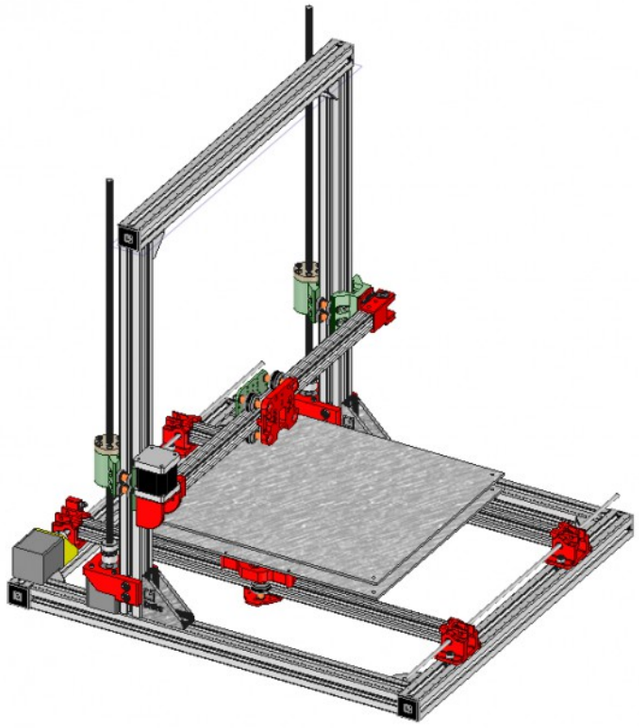


Figure 3.2.7. XZ Head printer. Source: http://3dmodularsystems.com/en/kits-packs/195-xz-axis-stabilitation-upgrade-for-scalar-xl-3d-printer.html [2019]

CORE XY

Core XY is a less popular but still interesting configuration printer. Some may argue that it should have it's own design category rather than being under the Cartesian one. Here, the printing bed moves along Z axis, while extruder moves around X and Y. Difference is that there are 2 motors controlling X and Y at the same time via a system of belts and clever mathematics. More about working principles of Core XY printers on slide "Further learning".

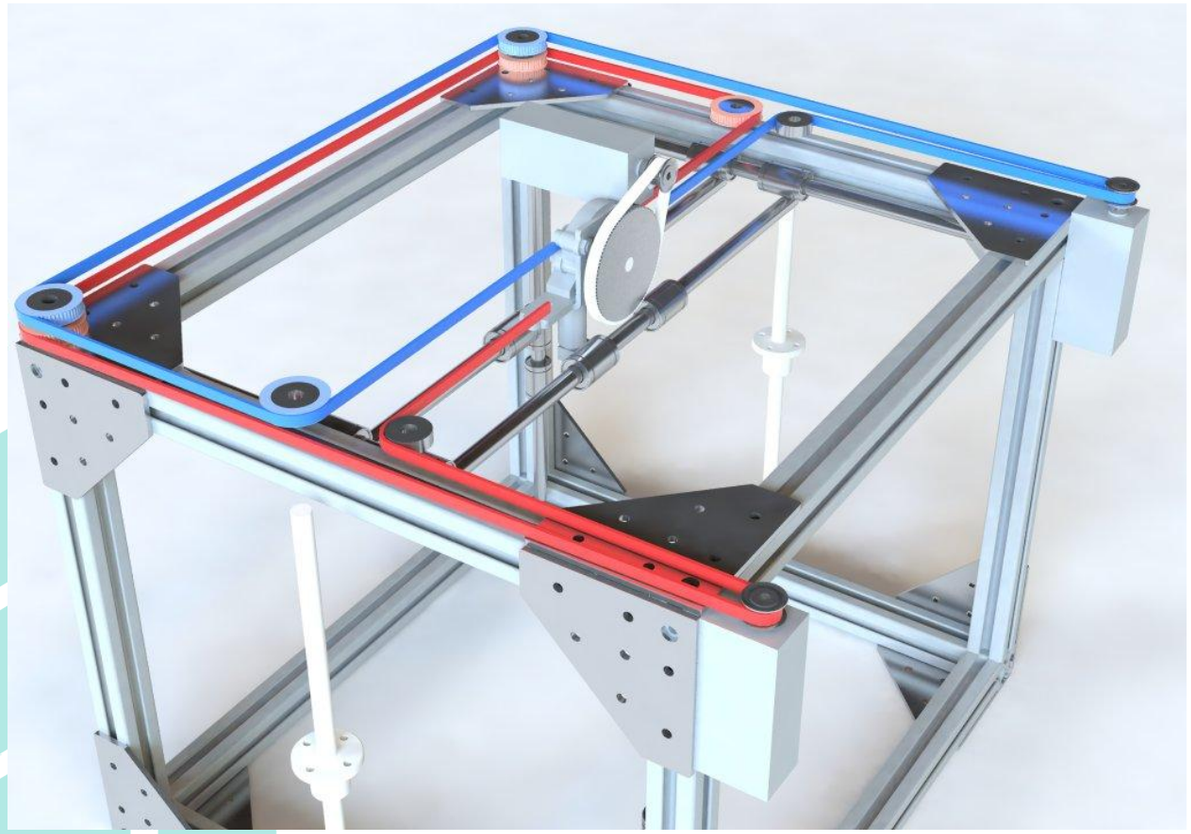


Figure 3.2.8. Core XY printer. Source: http://www.r2-3d.media-conversions.net/nextgen/Belt.Drive.html [2019]

PROS AND CONS OF CARTESIAN PRINTERS

Biggest advantage of Cartesian printers is their popularity. It’s easy to find help and support when problems strike your printer. Parts are also cheaper because of the huge market. A lot of them are bought already preassembled .
As with drawbacks, most of the issues are more specific to specific printers.

DELTA DESIGN

Delta printers, like Cartesian printers, also work within the Cartesian plane. What differs is how they navigate the print head within the build space.
A delta printer consists of 3 arms on individual rails that moves the extruder. Trigonometric functions are used to determine the location of the print head, therefore resulting in precise movements. These printers have circular printing bed and often are quite tall.

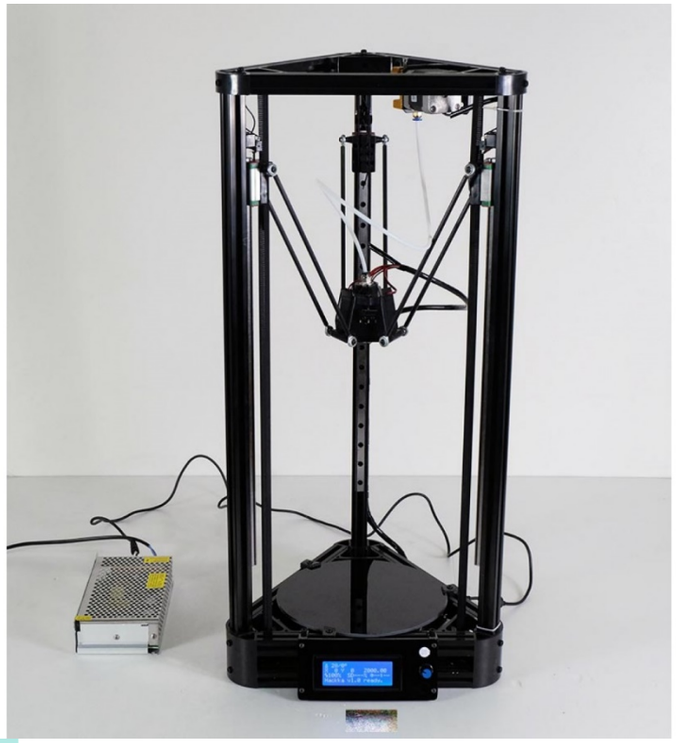


Figure 3.2.9.Delta 3D printer. Source: http://www.valuehobby.com/arduino-and-cnc/3d-printer/kossel-v1.html [2019]

MOTION DRIVE FOR DELTA PRINTERS

Delta printers have 3 individual axis where the 3 mounting points of print head are attached. These points then are belt driven by stepper motors, usually hidden in the bottom part of the 3D printer. This is the most popular motion drive system for Delta printers, although there are few others configurations available.

Figure 3.2.10. Motor location on Delta printer. Source: https://www.youtube.com/watch?v=mfjp9i9aJDg [2019]

SOME POPULAR DELTA PRINTERS

Here are two popular 3D printers at different price categories – Monoprice Mini Delta and SeeMeCNC Artemis 300.

Figure 3.2.11. MONOPRICE MINI DELTA
Source:
https://www.amazon.com/Monoprice-Calibration-Assembled-Preloaded-Printable/dp/B07CJQ3D6L [2019]

Figure 3.2.12. AND SEEMECNC ARTEMIS 300.
Source:
https://www.seemecnc.com/products/artemis-300 [2019]

PROS AND CONS OF DELTA PRINTERS

Huge advantage of Delta printers is their speed - the extruder is a lot lighter than in Cartesian printers so it can move around faster. Also, they usually have a tall build space, which can be useful in some situations. Where Delta printers lack is printing quality, which reduces when speed is increased. Also, most of available Delta printers are bought disassembled and the process of assembly can be quite tricky.

POLAR 3D PRINTER DESIGN

Apart from Delta and Cartesian printers, which take majority of the market, there are few experimental designs available too. One of them is Polar design. The extruder moves around Z, and the printing bed moves around X, but instead of moving on Y axis, the printing bed rotates.

Figure 3.2.13.Polar 3D printer. Source: https://www.tomsguide.com/us/polar-3d-printer,review-3206.html [2019]

Here is a video example of how this technology works.

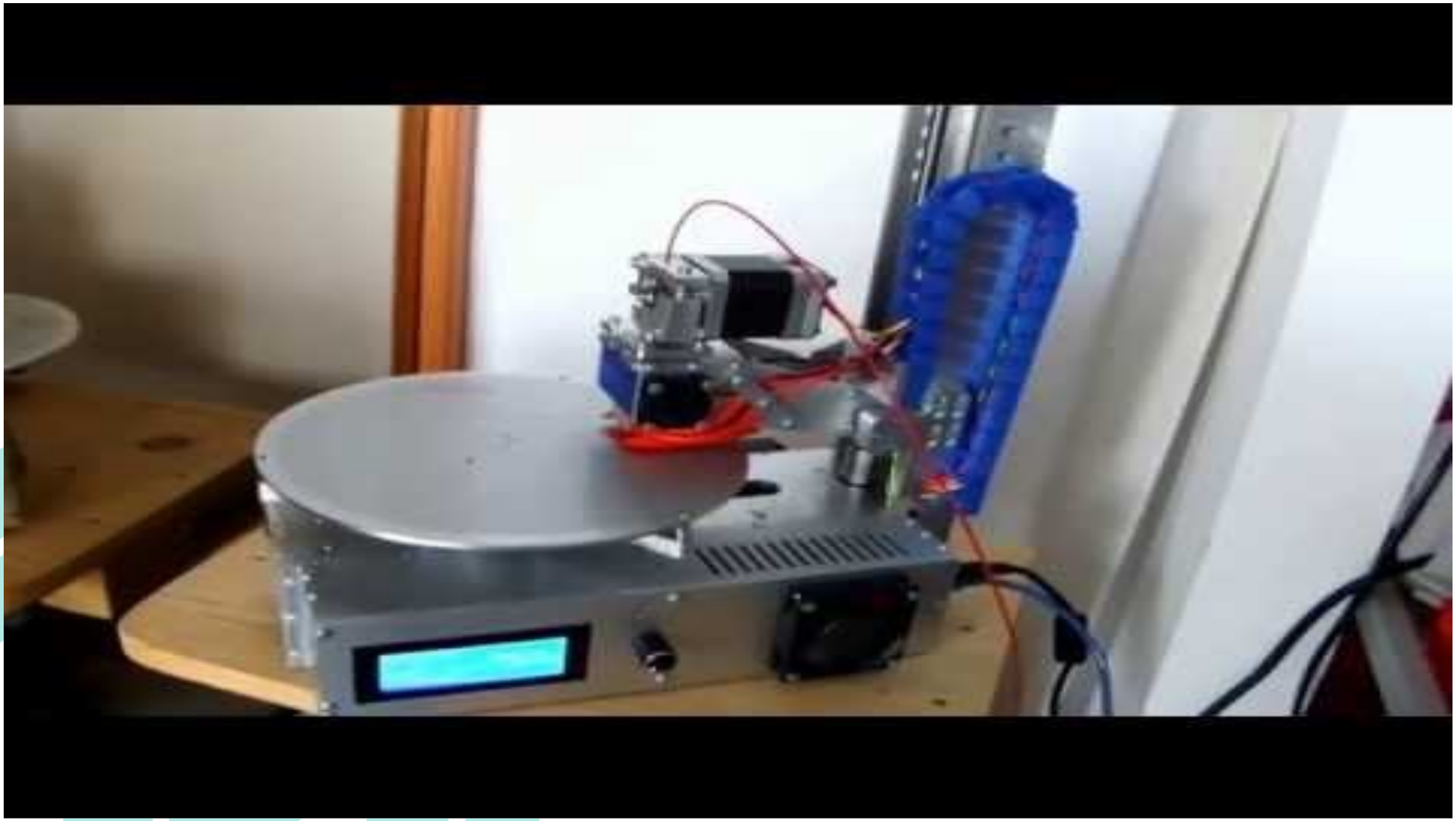


Figure 3.2.14.Polar 3D printer in action. Source: https://www.youtube.com/watch?v=O93z18w5SNU [2019]

3D PRINTER FRAMES

The frame is the part that holds whole 3D printer together. Most of the 3D printer frames are made from sheet metal, aluminum or plastic. It is also popular that parts of the printer are 3D printed. Most important factor of the frame is how rigid it is. The frame of the printer has to be very rigid as it will make the movement of the extruder more precise.

ENCLOSED OR OPEN

Enclosures for 3D printers are used for many reasons. One of them is safety, as there are moving and heated parts inside the printing area. Other is prevention from outside factors – temperature is very important in printing process. Also, some materials are affected by light.
Some of the printers are build enclosed, as for other there are enclosures available. If there are not, you can always construct your own from ,for example, acrylic glass.

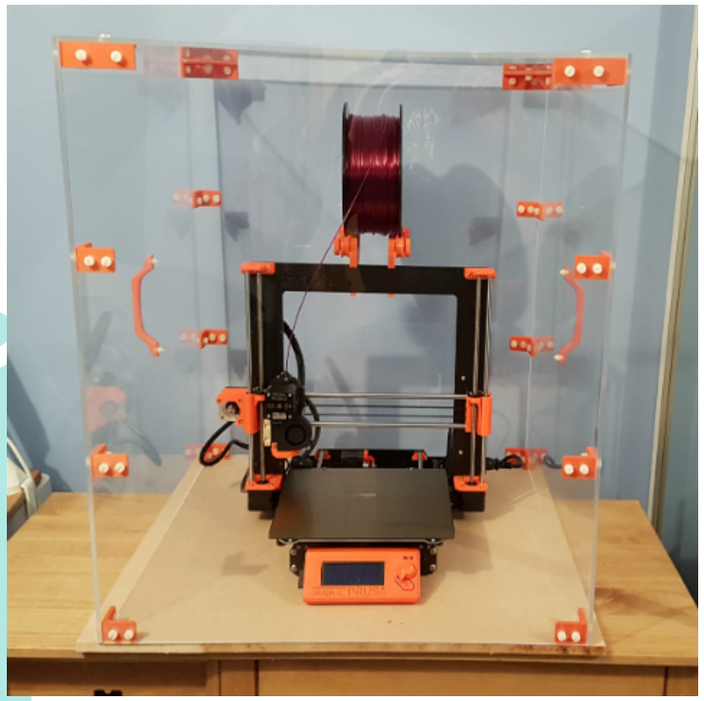


Figure 3.2.15.An enclosure. Source: https://www.theplasticpeople.co.uk/customer-stories/3d-printer-enclosures/ [2019]

FURTHER LEARNING

Core XY printer working principles
http://www.corexy.com/theory.html

A guide on all 3D printer parts with videos
https://www.matterhackers.com/articles/anatomy-of-a-3d-printer

In-depth guide on 3D printers, also from manufacturing point of view
https://3dprinting.com/what-is-3d-printing/#How-Does-3D-Printing-Work

TASKS FOR REFLECTIONS

Choose a 3D printer. It can be a random one from internet, or a printer available on sight. Take a good look at all its parts and answer these questions:

- What type of main design (Cartesian, Delta, other) is it? What configuration of the design it has?
- What type of extruder it has?
- What motion drive system is on each axis?
- What material/filament is used right now (if inserted)?
- What material frame it could be? Is it enclosed or open?
- What surface on printing bed is used?

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