Hotends

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The purpose of the hotend of a 3D printer is to melt the plastic that is fed into it, and deposit it in a controlled manner.

A hotend consists of a "cold side" which keeps filament as straight and cold as possible until it is fed into the "hot side", where the filament gets heated past its melting point via conduction from the heater block around it. Below the heater block is the nozzle, which reduces the diameter to its final width immediately before extrusion.

Key aspects of hotends to consider are:

- Cooling of the cold side
- Minimizing conduction of heat from the hot to the cold side
- Control of the heater block temperature against the cooling effect of cold filament going in and part cooling airflow
- Prevention of leaks on the hot side
- Wear resistance
- Rigidity
- Length of meltzone
- What nozzles are available

Structure

Cold Side

The cold side of the hotend is very simple: filament is guided through a narrow tube just larger than the diameter of the filament, and this tube is surrounded by (or itself made from) conductive metal (aluminum or copper) to draw heat away.

These can dissipate heat in three ways: a finned heatsink, a water cooling block, or conduction into a larger metal structure that acts as a heatsink.

At the top of the cold side is often the mounting structure for attaching the hotend to the toolhead, unless the hotend is more deeply integrated into the design of the toolhead.

At the bottom of the cold side, the filament gets delivered to the filament heatbreak, and any additional structural support for the hot side is attached.

Filament Heatbreak

The filament heatbreak moves filament from the cold side to the hot side, with the goal of minimizing heat transfer and preventing leaks.

On many older hotend designs, the filament heatbreak also is the sole support for the hot side, creating a conflict between maximizing structural strength and minimizing heat transfer.

Very old hotends have the heatbreak lined by a PTFE tube that goes all the way down to the heater block itself, which reduces friction and drastically reduces heat creep, but is a wear item and reduces the maximum temperature of the hotend.

The connection from the heatbreak to the hot side is an important consideration for reliability and performance.

- Thread-in heatbreaks: these occupy the top few millimeters of the heater block. If the heatbreak is monolithic then this somewhat reduces the effective length of the melt zone. If the heatbreak is bimetallic (a thin low-conductivity tube press-fit into a threaded copper slug) then melting performance is improved but this can potentially be a source of leaks.
- Brazed-in heatbreaks: these minimize the thickness of the low-conductivity metal along the filament path of the meltzone, but reduce repairability in the case of failures.
- Press-fit heatbreaks: often used in integrated heatbreak nozzles, these are similar to brazed-in heatbreaks but are a leak risk.
- Press-on heatbreaks: these do not intrude into the hot side at all and are pressed downward from the cold side onto the top of the hot side. These maximize the meltzone with minimal compromise, but if the pressure is insufficient then they could leak.

If the heatbreak is too conductive, the cold side will warm up too much, causing heat creep. Also if the heatbreak is too short, even if low conductivity, the cold side will also warm up too much, causing heat creep. Conversely, if the heatbreak is too long, the temperature transition between the hot and cold sides will be too gradual, resulting in mild amounts of heat creep that will increase required extruder force for a given flowrate even if it doesn't fully jam.

Structural Heatbreak

Older or more basic hotends use only the filament heatbreak to support the heater block, but this reduces the strength and stiffness of the hotend, increasing deflection of the nozzle tip under high acceleration and making the hotend susceptible to damage when tightening nozzles or if the nozzle rubs on the bed or print.

To mitigate this issue, some hotends are designed with additional structural reinforcement.

There are several methods for this.

- Stainless steel tubes in compression with screws in tension (Mosquito)
- Standoff screws made of titanium (Rapido 2)
- Tensile filament heatbreak with tubes or zirconia columns in compression (Dragon ACE)

- Truss (v9, Tricorn)
- Titanium tube with cutouts (Chube)

Heat Block

The heat block has four main considerations: length, material, heater type, and temperature sensor.

The longer the meltzone, the better the hotend will be at bringing filament to temperature before it reaches the nozzle tip. In addition to enabling higher peak flowrates, longer meltzones enable you to have more consistent temperature when flowrates vary (reducing variation in sheen on surfaces) and also let you run lower temperatures for a given flowrate, which can be good for high temp engineering plastics. Longer meltzones will require more PA and will ooze more if the filament isn't perfectly dry.

The material affects usability more than melting performance. Aluminum heater blocks should not be used above 270 degrees C because strength falls off dramatically. Copper has high thermal conductivity and matches the coefficient of thermal expansion (CTE) of brass and copper. However, it is expensive and more difficult to machine. Steel heater blocks have great hardness and high temperature capabilities but they match the CTE of brass nozzles poorly, matching better with tungsten carbide. It has lower thermal conductivity, which can make temperature regulation more difficult.

Heaters are either sufficient or insufficient. Cylindrical cartridge heaters are versatile and easy to replace with cheap or high-end versions. They're somewhat bulky but perform well because their power doesn't change much with temperature, making temperature control simpler. PTC ceramic heaters are small and light, but their power drops off as temperature increases, which makes it more difficult to control temperature. They come in two forms: cylindrical ones that provide 360 degree heating of the filament but are more prone to breaking, and planar ones which don't heat as evenly but are more robust and replaceable. Nichrome or Kanthal wire is occasionally used. This is high performance with constant power, and it can fully surround the filament path, but it makes replacement difficult.

Draft Shield/Sock

Heater blocks are usually covered with insulation in order to improve temperature uniformity across the heater block, reduce the power required to maintain temperature, and reduce the cooling effect of part cooling air.

On almost all hotends for sub 300 degree C temperatures, this is a "sock" made of silicone that tightly fits around the heater block and usually attempts to cover at least some of the nozzle. The lifespan of silicone is basically unlimited at lower temperatures, but it gradually degrades at temperatures approaching 300 degrees C.

For higher temperatures, the hotend can be wrapped in fiberglass or mineral wool, which is then secured with Kapton or aluminum tape, or silicone tubing. Alternatively, low-thermal-conductivity metals like stainless steel or titanium can be used to deflect cooling air without conducting much heat away while resisting unlimited temperatures.

Nozzle

Different hotends use different nozzles. E3D V6 is the most common standard, but there are many variations. Some nozzles come with integrated heatbreaks and even integrated heatsinks, which eliminates the need for hot tightening but can still leak from manufacturing defects. Some nozzles are also integrated into the heater block, which can improve thermal control of the nozzle itself but limits selection.

Issues

Heat Creep

Heat creep occurs when filament is allowed to reach its softening temperature on the cold side of the hotend.

When this occurs, as the filament gets pressed from behind by the extruder, the softened filament bulges and jams against the walls of the filament path. No matter how hard it is pushed, flow will completely stop.

Inexperienced 3D printer users may think it's a clogged nozzle but there is actually no obstruction in the nozzle opening.

Heat creep can be caused by insufficient cooling (or actual heating) of the cold side, from a filament heatbreak that is too conductive, too short, or counterintuitively too long..

Leaks

The pressures inside a hotend are absolutely monstrous. If the interfaces sealing the molten plastic in are not joined closely enough, filament can and will leak out and form large blobs of plastic that can destroy the hotend and even the entire toolhead.

When the nozzle and heater block materials are significantly different in thermal conductivity, it's important to tighten at or above operating temperature so that they don't loosen up.

Softer materials are easier to deform and create tight seals with, but they more easily fail completely. Use an appropriate torque wrench or torque screwdriver to tighten nozzles, as there can be a fine line between leaking and damaging, especially with CHT nozzles.

Structural Failure

On hotends where the filament heatbreak is the only structure supporting the heater block, it can easily be damaged. The only sure way to avoid this is to avoid hotends without sufficient support.

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