Journal of Trends in the Development of Machinery and Associated Technology
Vol. 19, No. 1, 2015, ISSN 2303-4009 (online), p.p. 189-192

DESIGN OF OPEN SOURCE 3D PRINTER EXTRUDER AND MODELLING OF THERMAL PERFORMANCE WITH FEA

Jerez-Mesa, R., Travieso-Rodriguez, J.A., Gomez-Gras, G., Freixedes, J.
Escola Universitària d'Enginyeria Tècnica Industrial de Barcelona. Universitat Politècnica de Catalunya. Mechanical Engineering Department.
C/ Comte d'Urgell, 187, Barcelona
Spain

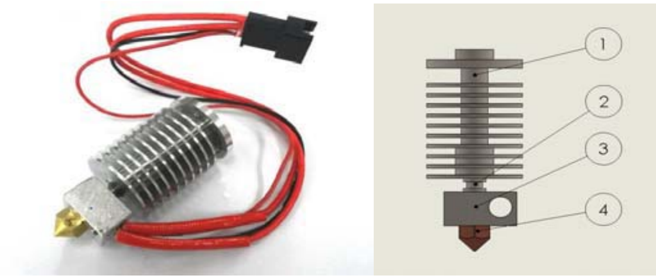
ABSTRACT
Open source 3D printers is the most selected choice made by ·d-printer for private households nowadays. Installation easiness and high availability of know-how about them are the key aspects to that success. The open-source nature of most of available 3D printers offer a perfect context for hardware innovation in the university sphere as well, allowing manufacturing researchers to improve overall printing process, not only during the deposition process, but also in terms of durability of the printing machine. 3D printers can be object of a more thorough design, because their non-profit origin makes them lack optimization and accuracy in some aspects. This paper tackles with a new design of liquefier, called Twist3D, based on the design of the widely extended RepRapBCN project's BCNozzle. A 3D printer liquefier must transmit heat to the thermoplastic material in order to extrude it, reaching temperatures above 200 degrees for some materials like ABS on the tip of the nozzle. The design of the heating process must comply with keeping the balance between proper heating of the material and controlling the temperature along the extruding body, so that the printer itself is not harmed for overtemperature. On the other hand, the design must guarantee that the melting front is located in an intermediate point between the nozzle tip and the entrance of the raw material, to minimize pressure drops in the system, and so decreasing the demanding energy to the feeding motors. An alternative design of the heating system is proposed in this paper and simulated with FEA tools in a printing scenario. The change of the dissipating fins are determinant to the volume of heat dissipated, and therefore, for the quality of the process and improvement of the printer's durability.
Keywords: 3d printing, FDM, extruder, nozzle, liquefier, reprap, heat transfer

1. INTRODUCTION
3D printing is one of the main drivers of innovation in the manufacturing technology field worldwide. This paper focuses on open source 3D printing systems specifically, and their potential to cover domestic needs. As it is an intuitive technology, ease to learn, cheap and self-reproducible, desktop 3D printers (i.e. non-industrial 3D printers) have all the characteristics required to solve possible situations that might emerge during our day-by-day life. During the next years, we will very probably witness the development of new desktop 3D-printing systems that will enable anyone to design and manufacture a certain piece, either to cover a need, or simply for inventive pleasure.
With the aim of contributing to the achievement of these visionary trends, critical parts of currently commercialized 3D-printers, such as the liquefier module, should be improved. The fact that many of these commodity 3D-printers are open source, involves the fact that they can be objective of a thorough revision and improvement, for many systems have been designed by amateurs. The advantage of this situation, is that those open-source systems suppliers give access to the design of the products they provide, and therefore, the improvement initiatives can be tackled.
In Barcelona, there is a project lead by the UPC, inspired in the Rep-Rap initiative, through which users are encouraged to develop their own 3D-printer parts or even create one from scratch [1]. Important results have been obtained, with very positive trends in terms of quality of developed systems. But in this context, the design of a fully effective and stable liquefying system has always

been the Achilles heel of the initiative, and at the same time very necessary, for controlling fluid mechanics and heat transfer of the overall process is basic for the final quality of the part [2]. With this motivation, a new extruder has been designed inside this open-source initiative, so that currently available systems may be improved.
This objective has been tackled in this study by carrying out a thermal analysis, through a FEA, of the BCNozzle model of the BCN3D+ printer, manufactured in the UPC's Centre CIM. A proposal of a new extruder geometry will be presented, so that the heat generated during the printing can be better used and distributed, thus improving the extrusion process efficiency. The result has been a new extruder called Twist3D.

2. METHODOLOGY

The liquefier is the part of the printer responsible for the extrusion of the semi-molten plastic, so that it can be deposited layer by layer into the manufacturing volume, thus generating the desired geometry. The input material is a thread of the chosen material, taken into a heated channel by different feeding systems. Most of open-source printers are configured so that two stepper motors activate a knurled axis that pushes the filament inside the liquefier, with the help of a pressing system [3]. As the material slides inside the liquefier channel, its temperature increases, over its glass transition temperature, and is then extruded through the tip of the nozzle. The extrusion diameter varies from one system to another, but is usually between 0.3 and 0.6 mm. The temperature of that nozzle must be slightly lower than the melting temperature of the material, so that the hot extrusion can be successful, and the material is not totally melted. Those temperatures obviously depend on the input material, which is usually PLA or ABS.



1. Heat sink (fins)
2. Heat barrier
3. Heating source
4. Nozzle

Figure 1. BCNozzle liquefier: image [1] *and parts* (*self-designed after* [1])

The material can be purchased in reels of filament, which makes it easy to be attached to the machine and feed the liquefier. That filament has usually either 1.75 or 3 mm. What defines the precision of the process is the nozzle diameter. The lower it is, the higher will be the precision, but on the other hand, less material will be deposited in each path of the printing strategy, so more passes will be needed in order to achieve the desired geometry. That means that choosing the nozzle diameter is the result of a balanced decision, looking for the correct equilibrium between printing time and model precision, depending on its final working conditions. For the development of an optimized BCNozzle liquefier, its present geometry has been analyzed, identifying some positive aspects that have been considered kept for the new design:

- Modular design shows great advantages in terms of versatility and favors heat dissipation. The different parts described in Figure 1 can be detached, and reattached thanks to their tapped surface.
- The heat barrier, made of stainless steel, is considered a good solution as main physical limit to prevent heat conduction towards the upper part of the liquefier.
- In line with the modular conception of the liquefier, the removable nozzle allows to change easily the extrusion precision and makes easier the maintenance of the liquefier by allowing to remove possible plastic blockages consequence of an incorrect extrusion
- Forced convection must be kept, especially for ABS printing, because of the higher temperatures needed.

The improvements proposed for the described liquefier has a double objective: increasing heat dissipation of the whole system in order to protect the hardware of the machine, i.e., being able to heat the nozzle to the maximum temperature needed, but making sure that the upper side of the liquefier remains at ambient temperature. And, on the other hand, to succeed in shifting from prototyping to real manufacturing with these open-source, by acquiring a more accurate knowledge of the thermal process [4]. The strategy of reconfiguration lays in the fact that the design of the heat sink plays a key role in heat dissipation. Two actions are taken in consequence,

- Reducing the external diameter of the heat sink, thus reducing the heat transfer area. That way, conduction from the nozzle will be reduced, and it will have to dissipate less heat.
- Increasing the contact surface between the fins of the heat sink with the circulating air. A new configuration of the fins is proposed, by redefining their geometry not as parallel cylinders but as a helix.

The new proposed geometry was represented in SolidWorks®. The new shape of the heat sink fins gave the name to the new design: Twist3D. This new design was implemented in the COMSOL Multiphysics 4.4 FEA software. The software has a great availability of analyzing modules. The following modules were chosen in order to create a virtual environment, selecting processing parameters, making the calculation and analyzing the final results:

- 3D analysis module.
- Conjugate heat transfer module + laminar flow modules. They allow to make an analysis analysis of heat transfer in solids by conduction and convection with the surroundings.
- Stationary mode, focused on working conditions of the 3D printer once the system has completed the preparatory functions and the printing process has already started.

Both liquefiers were processed with the FEA software, under the same conditions, with a mesh represented in Figure 2.

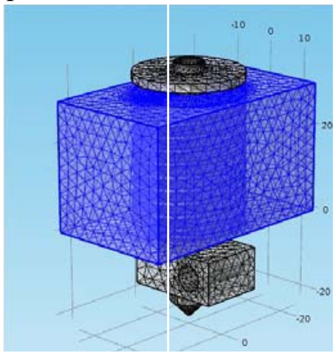


Figure 2. Mesh defined for the analysis of BCNozzle and Twist3D

3. RESULTS DISCUSSION

The computing of the implemented model described above, gave as first result a tridimensional isothermal map. It shows the temperature achieved on the solid surfaces (Figure 3). The maximum temperature achieved in the extruding body is higher in the BCNozzle (314,97K), about 8K higher than that achieved in the Twist3D liquefier (308,09K).

On the other hand, the tridimensional map of temperatures of the circulating cooling air evidences that the resulting air temperature is higher in the Twist3D extruding process (Figure 4). This fact can be explained because of the better heat transfer created by the newly defined fins. The helix configuration makes the air to be in contact for a longer time with the dissipating surface, and its higher final temperature means a lower temperature of the heat sink, as desired.

Last of all, streamlines of the cooling air are obtained (Figure 5). They represent the ways the air moves around the heat sink. Streamlines in the Twist3D evidence a higher contact of the cooling air with the fins, as their advance inside the refrigerating body is considerably higher. This result supports the fact that heat dissipation is better with the Twist3D liquefier observed in Figure 4.

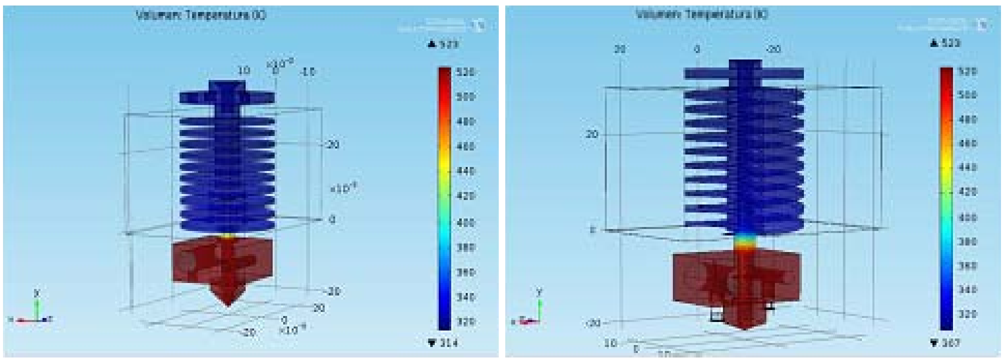


Figure 3. 3D isothermal map of extruding liquefiers. A- BCNozzle, B-Twist3D

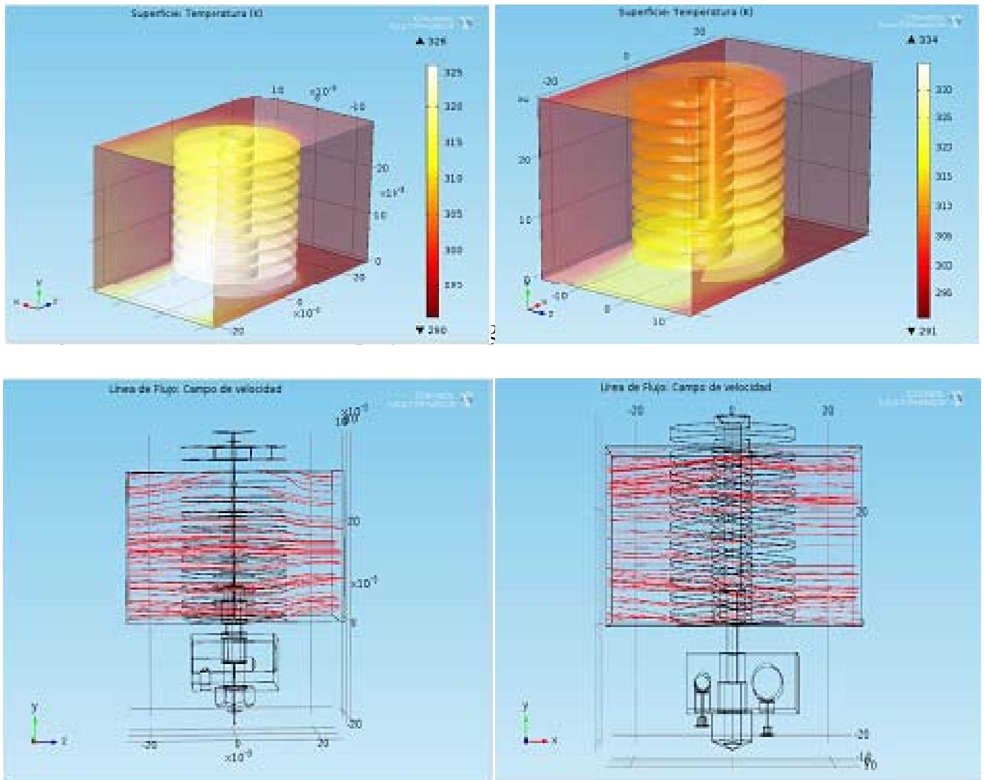


Figure 5. Streamlines for air flow around heat sink. A- BCNozzle, B-Twist3D

4. CONCLUSIONS

The FEA of basic heat transfer mechanisms of the BCNozzle and the new design Twist3D give light to the next conclusions:

1. The highest temperature achieved during the printing process with the Twist3D liquefier, is 8K lower as the one obtained with the BCNozzle.
2. The heat barrier in the Twist3D produces a great difference of temperature between the heating module and the heat sink. The security of the whole system is increased, and it would allow to use a wider range of materials with higher extruding temperatures.

5. REFERENCES

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