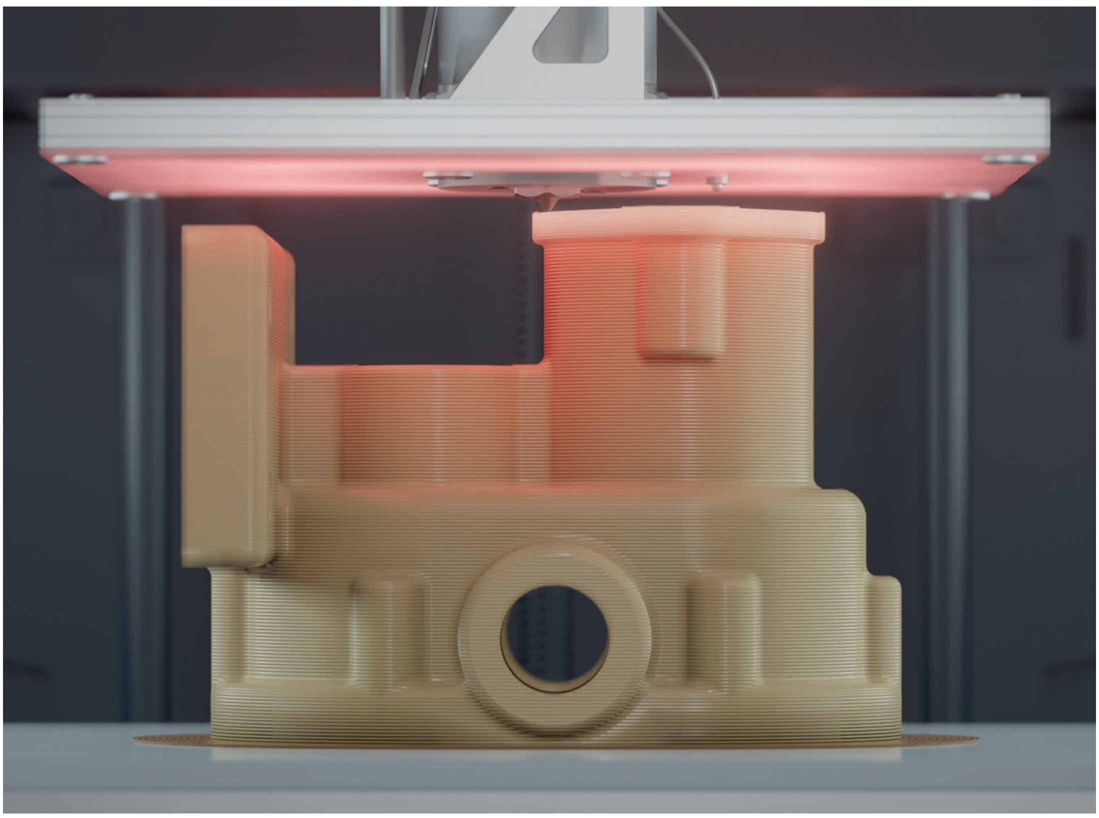
Targeted Heating of High-Performance Polymers

Thermal Management Plays a Crucial Role in 3D Printing of High-Performance Thermoplastics

When printing high-performance polymers such as PEEK, stresses occur in the component due to the relatively high printing temperature and the changes in the material structure. These stresses can lead to microcracking, warping, cracking and ultimately to component failure. In the Smart Printbed project, a system was developed to minimize these influences and also save electrical energy.



For optimal thermal management, the zone heating system in the Apium P220 3D printer relies not only on heating the print bed but also from above

High-performance thermoplastics are characterized by many technically relevant properties. They are strong, light, thermally, chemically and biologically resistant. Thus, they can be autoclaved and disinfected, which makes them versatile in the field of medical technology. However, the properties make processing of these polymers difficult. Reason enough to research a method for additive processing in a ZIM project at the Institute of Materials and Processes (IMP) at Karlsruhe University of Applied Sciences, Germany, and Apium Additive Technologies GmbH, Karslruhe, Germany. The plastic in question is polyetheretherketone, or PEEK for short, a thermoplastic of a partially crystalline nature. Partial crystallinity means that the solidification of the plastic is accompanied by a change in volume. There are different approaches to counteract this volume change.

Most printer manufacturers heat the build space to prevent the polymer from assuming unfavorable stress conditions. However, global heating means little control with components of varying thicknesses, as well as high non-directional energy consumption.

In this project, Apium developed a now patented zone heating solution that provides the component with the energy it needs to solidify in a uniform and stable state. This means less time loss to start the production because the build volume does not need to be heated, less energy consumption and greater control over the individual printing zones.

The Zone Heating System Supplies Energy Only Where It Is Needed

IMP complemented this project with an innovative print bed in which partial heating, cooling and temperature measurement is possible. This further improves part quality by more precisely directing energy into the part and saves up to 90% of the primary energy compared to a conventional print bed. **Figure 1** shows a schematic sketch of the print bed. The segmented print bed consists of 25 individual, 2 x 2cm Peltier elements, which combine in a mosaic-like manner to form the complete print bed.

Due to the chessboard-like structure, it is possible to heat only those areas that are actually in contact with the component. Especially with small components, this can significantly reduce power consumption, since the entire print bed does not have to be kept at temperature.

Design of the Smart Print Bed

Another step towards saving electrical energy lies in the Peltier elements themselves: when heating, they make use of the heat pump effect and save up to another 10% of primary energy, compared with conventional ohmic resistors. By reversing the direction of current flow, Peltier elements can be used not only for heating but also for cooling. This reduces the cooling time after printing and also enables even more precise thermal management of the printing process. The third major advantage of using Peltier elements is that – due to the Seebeck effect – they can also be used as thermocouples for process temperature monitoring. The Seebeck effect can be seen as a reverse Peltier effect. This time, a temperature difference leads to a small electrical voltage, so that conclusions can be drawn about the temperature. By the way, this effect is also used by every thermocouple. Since either heating/cooling or measuring can be performed sequentially, there is always an alternation between a heating/cooling cycle and a measuring cycle.

However, before a Peltier element can be used to measure temperature, the characteristic parameters of each element must first be determined. In the measurement setup, a heat source and sink are each placed on one side of the Peltier element and the respective temperatures are kept constant so that a certain temperature difference is established and the voltage resulting from the Seebeck effect can be »

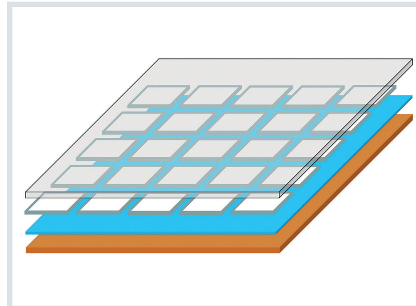


Fig. 1. The Smart Printbed can heat, cool and measure temperature. The schematic sketch of the print bed shows the structure, which consists of 25 individual Peltier elements

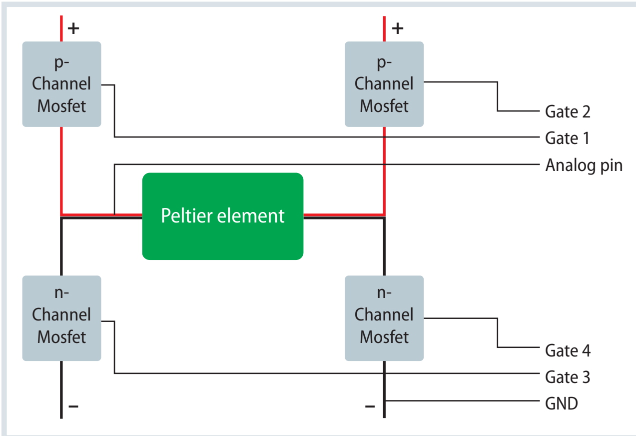


Fig. 2. It all depends on the correct wiring: Only with a bridge circuit can the Peltier elements assume all three operating states (heating, cooling and measuring) Source: Karlsruhe University of Applied Sciences; © graphic: Hanser

measured. The voltages measured due to this effect vary between 123 mV and 338 mV in the test setup.

In practice, this means that the Seebeck voltage must be determined experimentally for each element individually. This requires a certain amount of effort, especially in the final assembly, to ensure that the technical advantage is not offset by excessive manufacturing costs. In practical implementation, in addition to determining the current-voltage characteristic resulting from the Seebeck effect, it is particularly important to connect the Peltier elements correctly so that they can assume all three operating states (heating, cooling and measuring). The Peltier elements are constructed in a bridge circuit consisting of a total of four Mosfet (metal-oxide-semiconductor field-effect transistor) (**Fig. 2**). The two Mosfet installed between the positive conductor and the Peltier element are p-doped, while those between ground and the Peltier element are n-doped. The Seebeck effect, e.g., is tapped between Mosfet 1 and the Peltier element. The control is done via an Arduino, which reads the temperature of the individual heating elements.

Optimal Thermal Management Requires Perfect Interaction

Thermal management is crucial for the stability of the printed product, especially for semi-crystalline polymers such as PEEK. The control board handles communication between the board, microcontroller and zone heater. Their interaction is crucial for an optimal printing result. If components are printed partially crystallized, they are in a partially stable state. As soon as such components are exposed to a state of increased energy, for example increased ambient temperature and/or mechanical frictional heat, the remaining non-crystallized areas will also recrystallize. This behavior can be compared to the bubbly bottle in the freezer. As soon as the water freezes to ice, the required volume changes and the bottle breaks. In the case of semi-crystalline polymers, the workpiece bends and loses its shape in the best case, and cracks form in the worst case. For this reason, it is advisable to be able to adjust the processing temperature during printing in such a way that the component produced is in its stable phase after the printing process and can be used without hesitation. Optimized thermal management is therefore necessary not only on the part of the print bed, but also on the part of the print nozzle (**Title figure**).

Large components require different processing temperatures than small, narrow components. A specific adaptation is not possible with other systems that require a general ambient temperature setting is not possible. Together with the IMP of the Karlsruhe University of Applied Sciences the Polytechnic School of Engineering of the Universidad de Oviedo, Spain, and Apium Additive Technologies GmbH, it was possible to demonstrate the significance of such a targeted temperature control within the framework of a ZIM project, funded by the German Federal Ministry of Economics.

Conclusion

In order to print high-performance polymers such as PEEK in an energy-efficient manner while making maximum use of the positive material properties, optimized thermal management is crucial. To achieve this, a print bed consisting of Peltier elements was developed in which the Peltier elements can be controlled individually and can heat, cool and measure the temperature segment by segment. The patented zone heater ensures ideal printing conditions and good layer adhesion on the printhead side. The decisive advantage is that neither the entire build space nor the entire printing plate needs to be heated to obtain a component made of fully crystallized PEEK. ■

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Acknowledgment

This cooperative project was funded by industrial joint research (BMWi/AiF). The authors would like to thank the German Federal Ministry of Economics and Technology (BMWi) and the German Federation of Industrial Research Associations (AiF) for their financial support of the project.

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