Mechanically engineering a custom thermal cycler

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Introduction

A thermal cycler is used to complete the polymerase chain reaction in order to amplify DNA samples for examination and testing. This project provided the opportunity to build a low-cost thermal cycler for use in classrooms or labs with low budgets for science and technology. It was originally invented to avoid the tedious task of manually moving DNA samples through multiple water baths. "Thermal Cycler" (n.d.) and Zou et al. (2002) offer, "Thermal cycling steps were performed manually, involving repeated transfers of DNA samples among three large water baths set at different temperatures for denaturation (95 °C), annealing (55 °C), and extension (72 °C)." These temperatures have been tested and found to be optimal for each stage in the polymerase chain reaction. Research by Hecker and Roux (1996) states, "The standard PCR run at suboptimal annealing temperature (55 °C) yielded the desired product." Engineering a custom thermal cycler included the use of a heating element created by running electricity through a resistor and a cooling process which used a heat sink and fan. The design revolved around the heating elements, cooling elements, and electrical components due to their significance in the project. This was all accounted for when determining the size and shape of the product.

Materials and Methods

This project was started with the examination of an existing commercial thermal cycler, a miniPCR. The process implemented by that thermal cycler was replicated in the engineering process of a custom thermal cycler. As shown in Figures 1 and 2, the model was completely designed in Autodesk Fusion 360. The four aluminum pieces were milled with a computer numeric control (CNC) machine, which required computer-aided manufacturing (CAM) software to generate G-code.

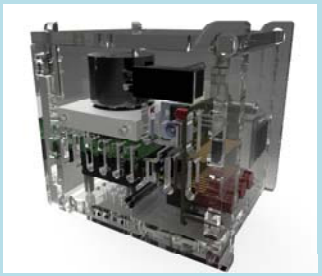


Figure 1 (above): This rendering of the model shows the printed circuit board, LCD, input ports, and power switch. The model is approximately 119 mm wide.

Figure 2 (above): This rendering of the model shows the aluminum components and the lid latching mechanism.

Materials and Methods

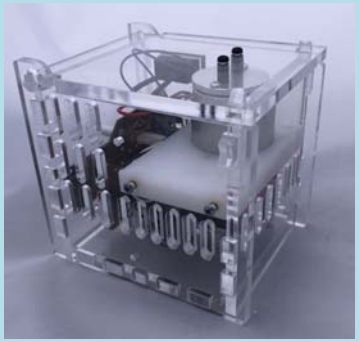
The CAM software in Fusion 360 was used to create facing, 2D pocket, and contour operations for individual elements of each part in order to generate toolpaths. The post process function was then used to create a file compatible with the CNC machine, the Nomad 883 Pro, which was communicated with via the driver software, Carbide Motion. Figure 3 shows the aluminum piece manufactured to hold the sample tubes. Ultra-high molecular weight plastic was also milled, while a cone to redirect fan air flow was 3D printed, and acrylic walls were laser cut. The wall sizes were dependent upon the size of the printed circuit board which was created by a colleague.

Figure 3 (above): This is the aluminum piece that holds the samples. It was milled from a cylinder and has a diameter of approximately 38 mm.

Results

Figure 4 (below): This shows the printed circuit board, LCD, input ports, and power switch.

Figure 5 (below): This shows the aluminum components and the lid latching mechanism.



After the completion of the design phase, the components were produced, and the thermal cycler was assembled. Figures 4 and 5 show the final product. Model verification was done by determining if all the parts worked. The thermal cycler was checked to make sure all components were held tightly together, and it was structurally sound at completion. Mechanical engineering and assembly were done correctly as the thermal cycler turned on without failure and was functional at the conclusion of the project. Due to COVID-19, there was not enough time to validate the project. Validation would have been tested by comparing DNA samples amplified between the custom thermal cycler and a miniPCR. Then, gel electrophoresis would have been used to determine whether the sample was amplified. Figure 6 shows an example of the expected results from gel electrophoresis. After taking samples from both the custom and commercial thermal cyclers, the gel electrophoresis would have quantified how much DNA was amplified. Brighter lines correlate to a larger sample size, which indicates more DNA amplification. The brightnesses would be analyzed and then compared between the custom thermal cycler and a commercial thermal cycler to determine the validity of the product.

Results

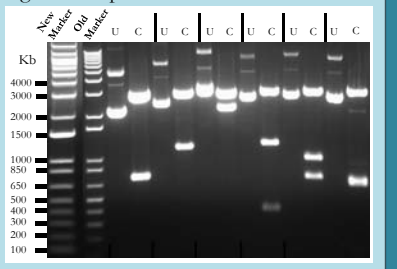


Figure 6 (above): This shows sample results of PCR by using gel electrophoresis.

Conclusions

A low-cost thermal cycler was mechanically engineered. The thermal cycler was built for 155 dollars, which is a significantly lower cost than the market value of 650 dollars. It was anticipated that DNA could be amplified just as well as in a commercial cycler even though time was not sufficient to find out. The steps taken to complete the project could be replicated to construct more thermal cyclers for educational use in a classroom or lab. The most challenging part about replication would be the use of the CNC machines as there were multiple attempts and lots of troubleshooting. In addition to the mechanical engineering aspect, other students contributed to the project through the design and production of the electrical components and for a computer interface to allow user-friendly communications. A design improvement in the future could include adding more sample wells, which would increase efficiency by amplifying more DNA is a similar quantity of time.

References

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