Team 507 Operation Manual

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EML 4552C: Senior Design 2

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Table of Contents

Contents

Project Overview

The objective of this project is to cool hybrid vehicles battery pack 5% more efficiently than the industry standard. Having a more efficient cooling method would increase corporate interest in hybrid vehicles, resulting in a decrease in carbon emissions. When developing a system there were 3 main functions to address: heat transfer, safety and efficiency.

Heat Transfer is the main component of the project. To cool the battery a liquid will flow through the battery in plates located between the pouch cells. The pouch cells hold the lithium which is what contains electricity. The liquid used is 50/50 coolant for its high heat transfer and it will not freeze in cold environments. The battery must be kept in the optimum temperature range of 30-40 ℃ or safety issues may occur.

Safety is very important for this project because Lithium-Ion batteries contain harmful chemicals. These chemicals are harmful for humans to get on their skin and even more harmful to get in the eyes or ingest. On top of being harmful to humans, the chemicals are highly reactive when exposed to oxygen. If the pouch cells that are used are punctured the chemicals will catch on fire. These fires are very dangerous and cannot be put out with water. The only way to put out the fire is to wait for the chemical reaction to finish. The pouches can also catch on fire from getting too hot. If the pouches reach a certain temperature a chain reaction called thermal runaway can occur and the cells will go into a state where the temperature of the cell continues to climb due to there being nowhere for the heat in the cell to escape to.

Efficiency is also an important aspect because the efficiency of the design has a significant impact on the cost of operation of the vehicle that it is implemented in. The two aspects of efficiency that are of concern are the weight of the cooling design and the pumping power required to move coolant through the system. The more weight that the cooling system has equates to more energy that will be required to move the vehicle. This will increase the fuel consumption of the vehicle, increasing the cost to operate it. The other component is pumping power. The power to run a coolant pump in a hybrid will take energy directly from the battery. This will decrease the amount of power that the vehicle has during a battery cycle. It is important to limit the pumping power as much as possible by reducing the head loss throughout the system.

The cooling system for this project is a liquid cooling system that uses thin cooling plates placed between the battery cells. The cooling plates have a coolant channel through it that flows coolant around and the coolant collects the heat from the cells and carries it away from the battery module. In total there are three cooling plates in the module with four battery cells.

Component Description

The project is broken down into two designs. An ideal cooling plate was designed using a manufacturing process called roll bonding. The roll bonding process takes two thin aluminum plates, and a mold is placed between the plates in the shape of the coolant channel. The plates are fused together at high temperature and pressure. The areas where the mold is do not get fused together, and compressed air is used to blow the mold out from between the plates. This leaves a coolant channel in the middle of the plates that can withstand high pressure. These plates are very light, and the process requires very little machining. Due to budget constraints, these ideal cooling plates were not achievable. Because of this, a different simplified version of the design that could be manufactured by the machine shop at the COE was developed. COMSOL simulations are being run on both the physical and ideal designs and physical testing will be performed on the physical design in order to validate the ideal design in COMSOL. Throughout this manual, both the “ideal” roll bonded cold plate design that could not be attained and the “physical” design that will be prototyped will be referred to.

I. Battery Pack Components

Figure 1: Nissan Leaf Pouch Cell.

The simplest component of the design is the pouch cell. The benchmark for the project will be the Nissan Leaf vehicle. The pouch cell can be seen in Figure 1. A Nissan leaf module has four of these pouch cells inside of it. The pouches have an average voltage of 3.8V and a maximum current of 33.1 Ah. The cells have dimensions 290mm length, 216mm width, and 8mm height. Inside of the module there are two cells wired as a pair in series and the two pairs are wired in parallel. The orange sections at the front of the cell are called the tabs. The cells tabs are the electrical connections. On the left side is the anode and the right one is the cathode.

Figure 2: Nissan Leaf module.

Figure 2 shows a Nissan Leaf module. The modules hold four pouch cells, and the goal of the module is to hold the cells in compression and protect them from being damaged. The modules are made from a thin aluminum casing. The terminals on the front of the module provide connections to the battery management system. The dimensions of the module are 300mm length, 220mm width, and 60mm height. The weight of the module is 3.8kg.

Figure 3: Nissan Leaf battery pack.

Figure 3 shows a 24kwh Nissan Leaf battery pack. The battery pack contains 48 modules and 192 pouch cells. The battery pack houses the modules which are tied together by the battery management system which consists of the electrical wires, terminal connections, and a computer that regulates the temperature, output current, voltage of each of the cells.

II. Ideal Design

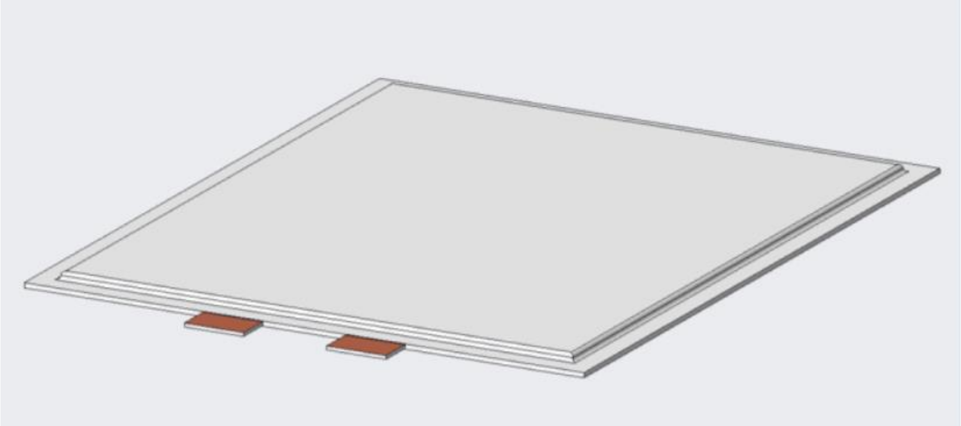


Figure 4: Pouch cell CAD model.

Figure 4 shows the pouch cell CAD model that was developed for the project. The cell has the same dimensions and material as the Nissan Leaf pouch cell shown in Figure 1. The pouch cell makes up the most basic component of our design.

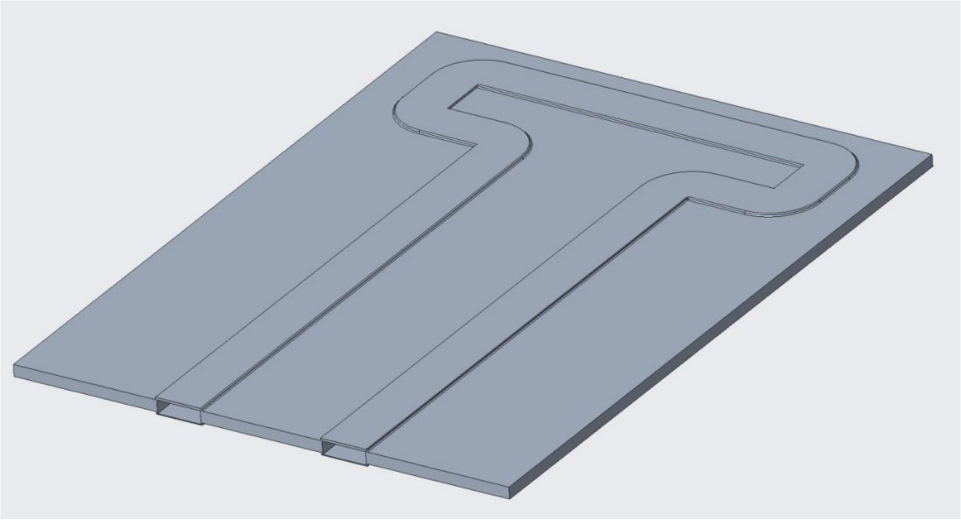


Figure 5: Cold plate design.

Figure 5 shows the cold plate that was designed for the cooling system. The plate is made of aluminum 6061. The plate has a thickness of 10mm. The plate’s length and width dimensions are equal to the Nissan Leaf pouch cell of 290mm by 216mm. The coolant channels that go through the plate have dimensions of 30mm wide by 8mm high. The coolant that is used for the system is 50-50 ethylene water coolant. The coolant classification is purple coolant. The left side of the coolant channel is the inlet, and the right side of the channel is the exit.

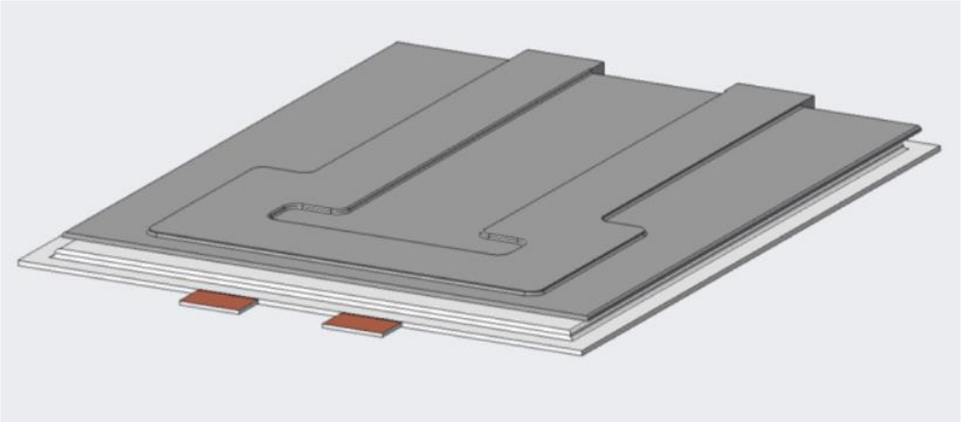


Figure 6: Cold plate on top of pouch cell.

Figure 6 shows how the cold plates will be placed in relation to the pouch cells. The inlet and outlet connections for the plates are on the opposite side of the cell's tabs. This keeps the coolant channel from interfering with the tab's electrical connections on the front of the module.

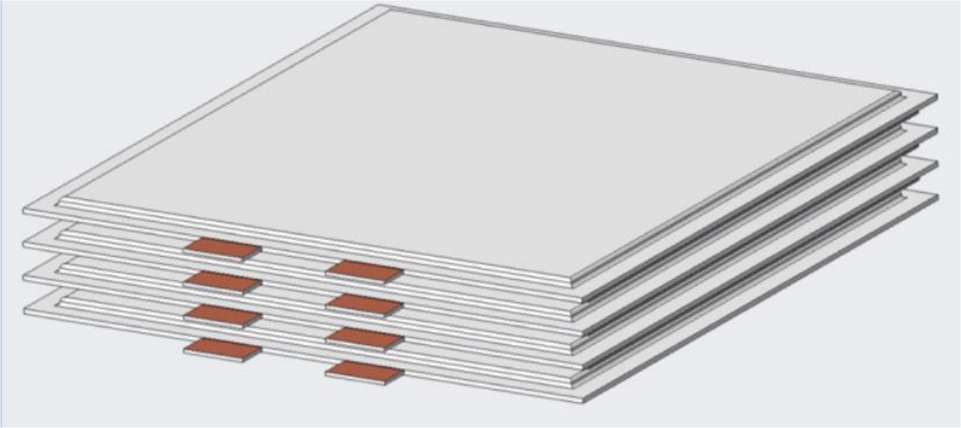


Figure 7: Plate and cell stacking.

Figure 7 shows how the cells and plates should be oriented within the module. The bottom of the stack is the bottom cell, which will be in contact with the module. On top of that is a cooling plate. The cells and cooling plates alternate stacking with each other. In total in the module there are four pouch cells and three cooling plates.

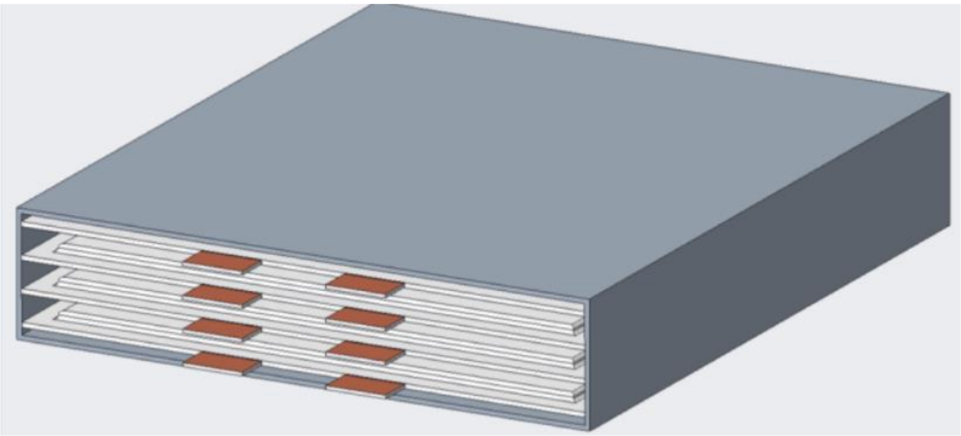


Figure 8: Module integration with cells and plates.

Figure 8 shows how the cooling design will fit within the module. The module that we are using for our design is an aluminum box. The module encases all of the pouches and cold plates. The electrical connections are made in the front of the module. The dimensions of the module are 300mm length, 220mm wide, and 80mm tall. In total the module weighs 4.5kg.

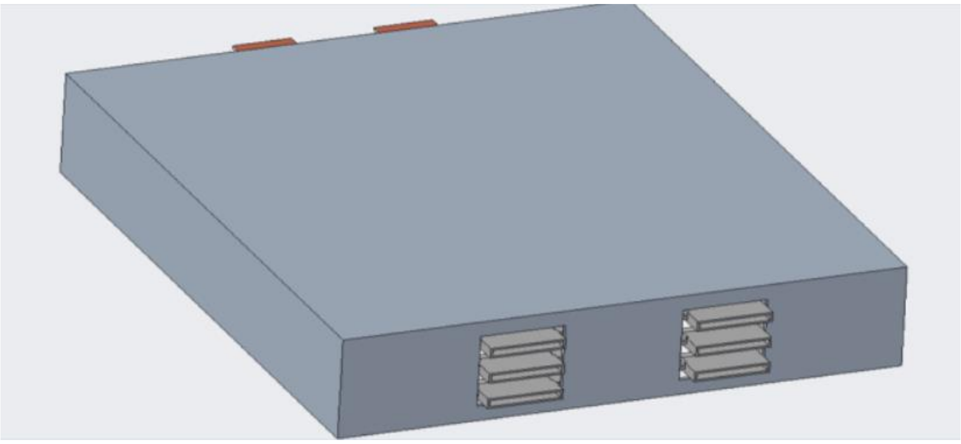


Figure 9: Coolant connections on module.

Figure 9 shows how the coolant channels are integrated into the module. There are two holes in the back of the module where the three inlet and three outlet connections come into the module.

III. Physical Design

Since the ideal cold plates could not be purchased, the design was slightly altered so that the machine shop at the COE could manufacture it. The key features of the physical design were kept the same as the ideal design such as the coolant channel shape and material for the plates. The thickness of the plates and the thickness of the coolant channel walls had to be altered due to the tolerancing of the machine shop's equipment. The inlet and outlet connections also had to be moved to the top of the plate because the plates could not be sealed together with the connections on the sides of the plates.

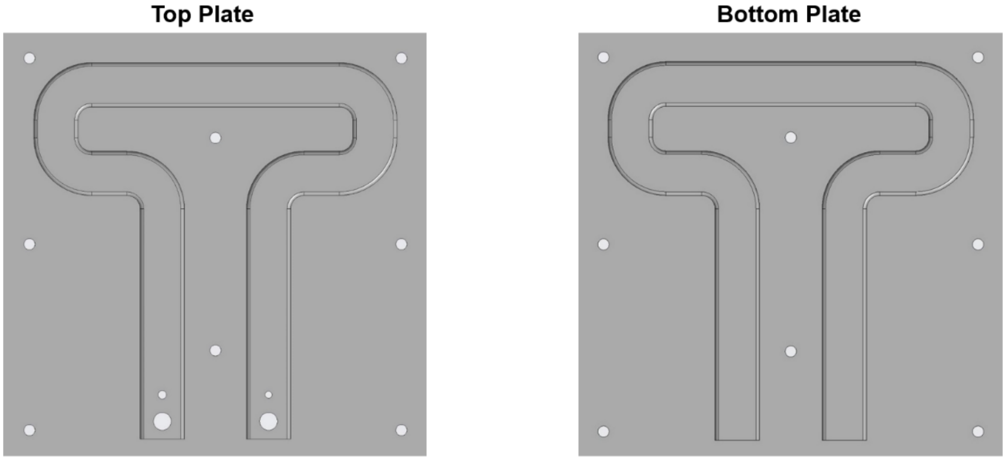


Figure 10: CAD model of physical plates.

Figure 10 shows the CAD model of the plates that were designed for the physical cold plate design. The plates are 12x12 inches in length and width and 0.5 inches in height. The plates are made of aluminum 6061. The top plate has holes in it for the inlet and outlet connections. The connections are 3/8” NPT push to connect fittings. The tubing that goes into the fittings is 3/8” outer diameter and 5/16” inner diameter. There are two holes above the coolant connections for the thermocouples. The thermocouples that were chosen have m6x1 threading. There are eight holes throughout the plate for the screws that hold the two plates together. The bottom plate is identical to the top plate except it does not have the coolant connection holes and thermocouple holes.

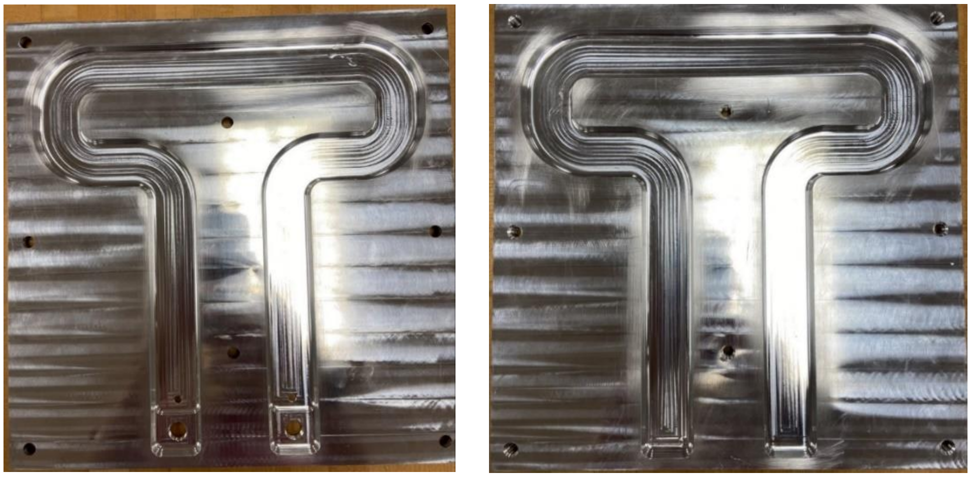


Figure 11: Physical plates.

Figure 11 shows the physical plates manufactured by the machine shop. The plates are identical to the CAD model of the plates that were sent to the machine shop. Refer to the drawings section for engineering drawings of the plates.

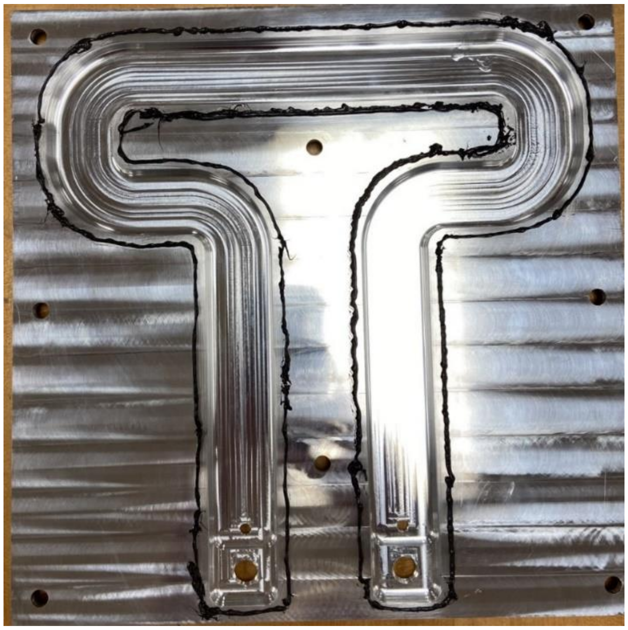


Figure 12: RTV gasket glue on the plates.

RTV gasket glue is used to seal the plates. This gasket glue is a silicon-based glue. The gasket glue is placed around the edges of the coolant channel. For more information on the gasket sealing refer to the integration section.

Figure 13: Assembled top and bottom plates.

Figure 13 shows the assembled cold plate. The top and bottom plates are sealed together with the RTV gasket glue and eight bolts. The bolts that were used are 1” long 5/16”-18 threads.

Integration

The testing of the system begins with the pump. The pump, pictured below, is powered by a power supply at 12 V. At regular power, the pump creates a flow of 2 gallons per minute (GPM), this exceeds the required flow so the amps applied will be increased. According to the supplier's manual, the lowest pump flow that can be achieved is 1.45 GPM with 8 amps used. Figure 14 shows the fittings that connect the pump to the tubing that was used to move the coolant around the system. The fittings are 3/8” outer diameter push to connect fittings with 3/8” NPT threads that screw into the pump. The pump’s electrical wires need to be connected to a DC power supply. The red wire connects to the positive and the black wire connects to the negative side of the power supply. Figure 15 shows how the tubing connects to the pump. The right side of the pump is the supply line, and the left side of the pump is the return side. The return line will go into a bucket with room temperature coolant in it. After the coolant passes through the entire system it will be discharged into an empty bucket. This is how the hot coolant will be separated from the cold coolant.

Figure 14: Pump connection fittings.

Figure 15: Pump supply and return tubing connections.

The pump will have nylon tubing connected to the pump. The tubing has 3/8” outer diameter and 5/16” inner diameter. This tubing is durable and able to handle pressure up to 100 psi. The pump that was used supplies 60 psi of pressure to the system.

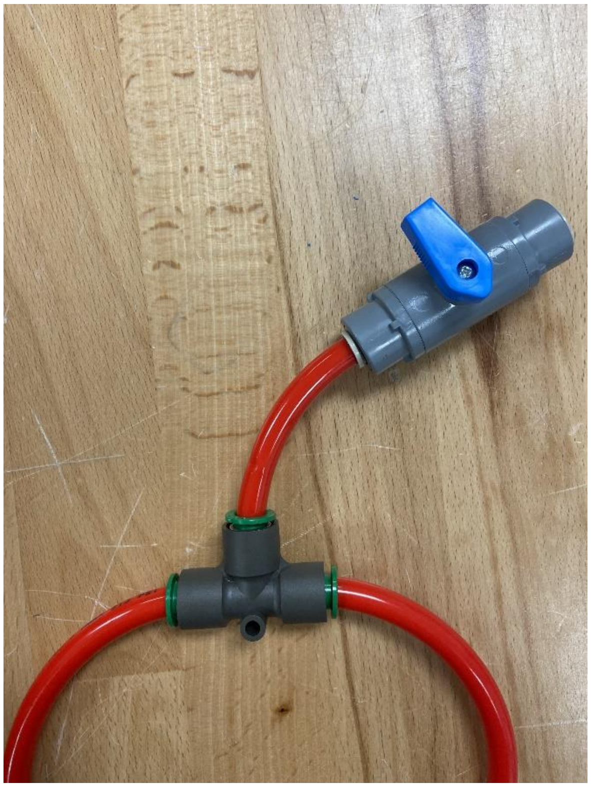


Figure 16: Joint and ball valve on supply line.

The flow of 1.45 GPM is still more than enough for the cooling system. Pictured above is the ball valve that will be applied to the tubing to reduce the flow. After the valve, the flow will be reduced to about 1 GPM. Then the flow will continue to the T-joint, this breaks the flow into two even streams that connect with the cooling plates. The connections to the plates are shown below.

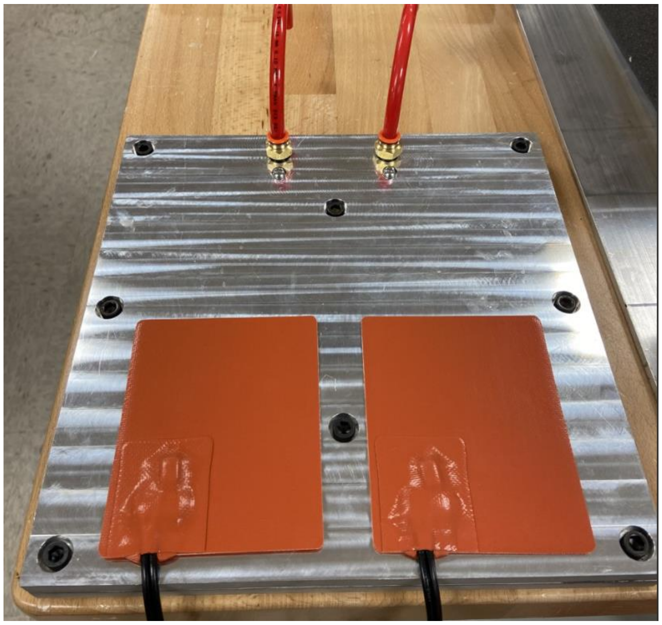


Figure 17: Heating pads on top of cold plate.

The cooling plate pipes feature inlet and outlet ports that utilize push-to-connect sockets for connecting the nylon tubes. Heating pads are located near the edge to simulate the heat generated by the battery tabs, which typically produce the most heat.

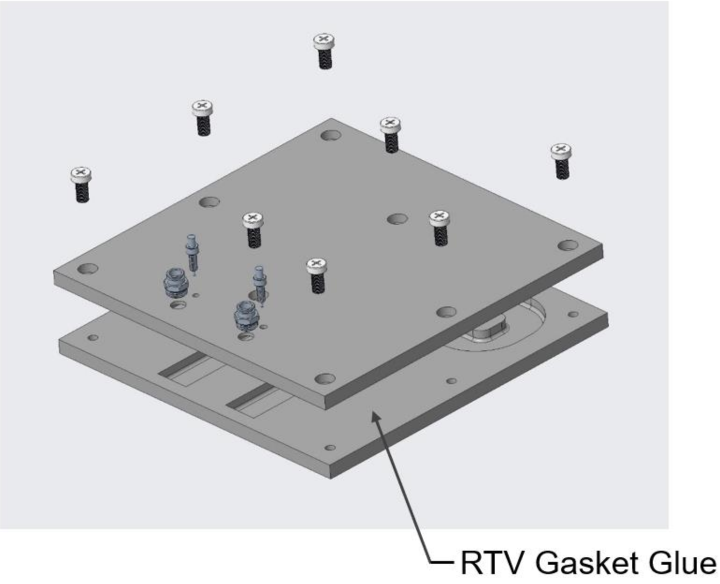


Figure 18: Exploded view of cold plate.

Figure 18 shows how the components of the plate should be assembled for proper use. The RTV gasket glue should be applied around the edges of the coolant channels. The glue should be spread on only one of the plates in a 2mm constant bead as shown in figure 12. After the glue is applied, the top plate should be placed directly on top of the bottom plate. Make sure to try and keep the plates from sliding on top of each other as they are being pressed together. Once the plates are lined up with each other the screws should be inserted into the screw holes and should be hand tightened. The glue takes one hour to settle. After one hour the screws can be tightened down further using a wrench. The gasket needs 24 hours to fully cure. After 24 hours the plate is sealed and ready to have fluid flow through it.

Prototype Operation

The pump should be connected to a variable power source to regulate the volumetric flow rate. With the power source set and turned on, coolant should begin to flow through the cooling plate. The ball valve can be used to further regulate flow rate. The heating pads should be plugged into a standard wall outlet. The power source should be used to regulate the heat generation in the pads until they replicate the known pouch cell heating behavior at the desired C-rate.

For a steady state test, the pouch cells should be turned on until the system's temperature reaches a steady temperature. Then, the pump can be turned on using the previously determined power setting and ball valve positions. The Arduino and code, used to take thermocouple temperature readings, should be turned on five seconds before the pump is turned on. For the transient test, the pump and heating pads should be turned on at the same time to observe the cooling behavior as the heating pads are heating up from room temperature. The Arduino and code should be turned on five seconds before the pump and heating pads are turned on. For both steady state and transient tests, the Arduino should continue to take temperature readings for at least a minute in order to simulate the time needed for some large hybrid vehicles to accelerate to higher speeds.

COMSOL Operation

COMSOL Multiphysics is an ideal software for creating time dependent simulations of this system. The following steps can be used to recreate a COMSOL simulation of the physical prototype. They imitate the heat generated in a pouch cell at a discharge rate of 5C.

The battery cell's geometry is 220x260x8 mm with tabs 30x30x3 mm with their centers positioned 50 mm from the battery cell's center plane. The cooling plates are modeled according to the drawings shown in Fig. 20 and 21. Two battery cells are modeled with the largest cooling plate underneath the lower cell, the medium sized between the cells, and the smallest plate on top of the upper cell. Each cell should have an internal plate at the exact center that is 160x120x2 mm. The battery cell, cooling plates, and internal plates inside each cell are modeled as “6061 aluminum”. The battery cell tabs are modeled as “copper”. The coolant and atmosphere are modeled as “ethylene glycol-water mixture” and “air” respectively.

The plate inside each cell should be a heat source emitting 500,000 Watts. One of the tabs on each cell needs to be a heat source emitting 1,000,000 Watts. The other tabs can be left alone. The thermal contact resistance between each cell and cooling plate is 1.6x10^-4 Ω•m^2. This is based on opaque aluminum surfaces in contact with 0.4 MPa of pressure. The thermal contact resistance between the tabs and each cell should be modeled as 0.

The “Heat transfer in solids and fluids” and “Laminar fluid flow” modules are the only physics modules that need to be included. The fluid flow in the cooling plates can be modeled as laminar with a constant flow rate of 0.2 m/s. The study should be “Time-dependent” with the time set from 0 to 50 seconds with a step size of 1 second. The mesh should be set to “Slightly coarse” in order to optimize simulation run time.

Troubleshooting

To investigate for issues, the battery pack can be found under the vehicle. One common error is that the gasket glue wears off creating leaks in the system. To detect this problem, one can inspect the area beneath the vehicle for any signs of coolant leakage from the battery, or alternatively, monitor the coolant levels to check for any abnormal usage patterns. Another issue is the nylon tubing is tough and hard to maneuver. But when the tubing is heated in boiling water the tubing is easier to maneuver. Other issues may occur, like corrosion or small clogs. These issues are hard to notice but the user might notice the vehicle running less efficiently over time.

To ensure the best use of the product, ensure that the gasket glue is applied to the edge of where the channel begins on the plate. The gasket glue does not need to be applied to the whole area of the plate, only on the edge. Do not apply too much gasket glue to the plates. If there is too much glue it can make the plate stick up higher in areas with more glue which can cause small holes in the sealant. If a plate is not sealing properly and the user is having issues with leakage, the plate will need to be taken apart and the RTV seal will need to be scraped off and reapplied. Figure 19 shows what a proper RTV seal should look like after the plates have been secured together. After the plates are secured together the glue should spread out to approximately 5mm wide.

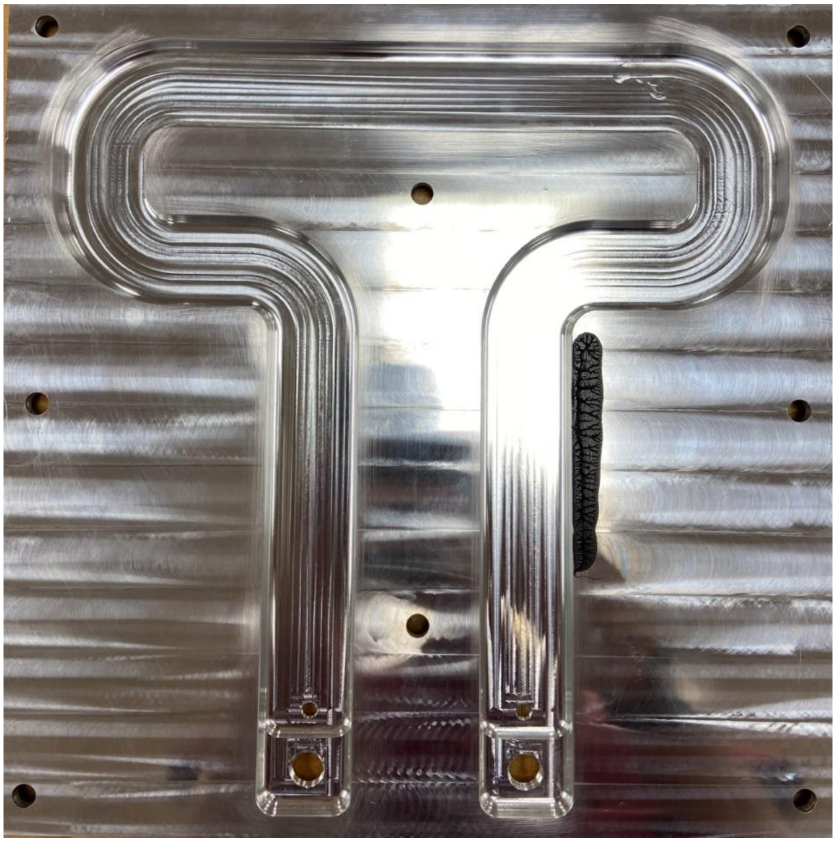
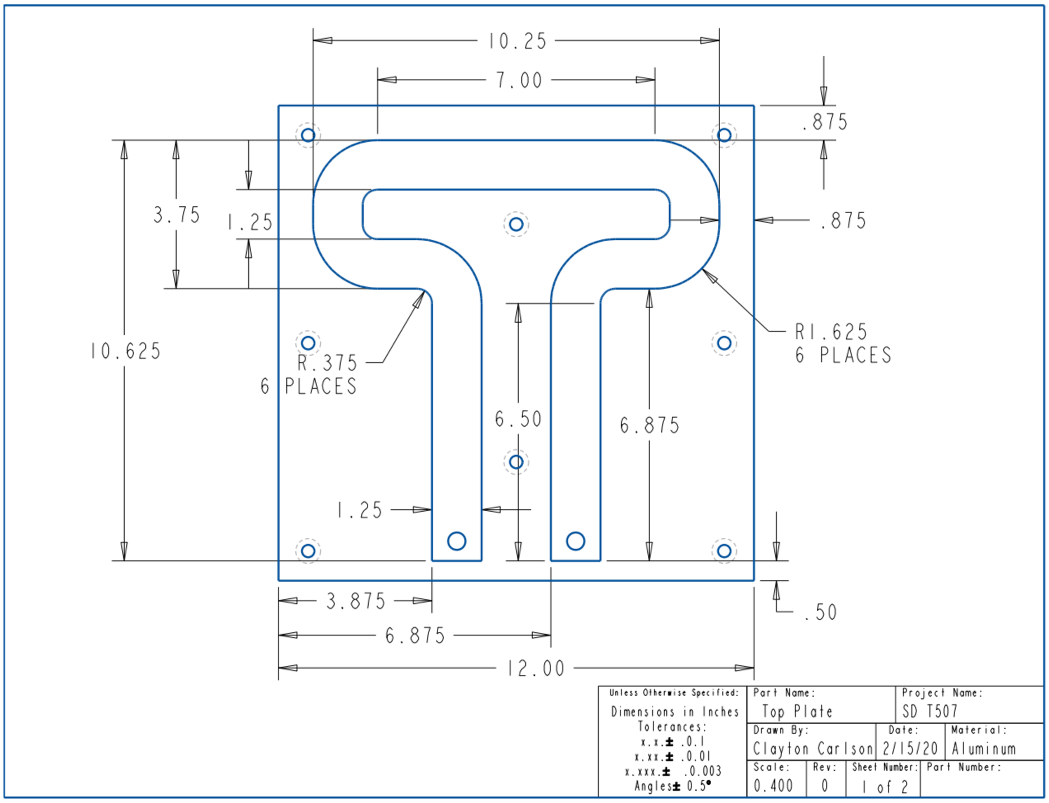


Figure 19: Proper RTV seal after plates are joined.

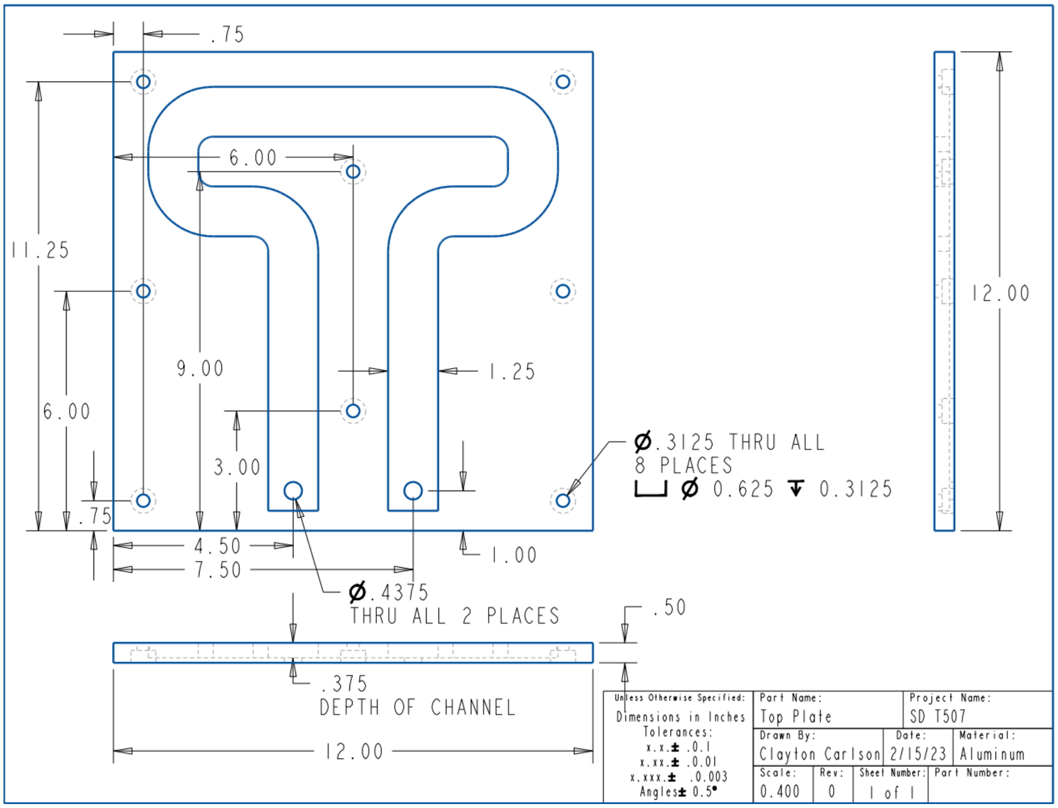
Other common issues that the user may experience during testing are leakages from the push to connect fitting threads and thermocouple threads. An easy solution to stop the leaking is to wrap teflon tape around the threading. The teflon tape should be wrapped in the same direction that the threads screw in for proper installation.

Part Drawings



Unless Otherwise Specified:
Dimensions in Inches
Tolerances:
x.x.± .0.1
x.xx.± .0.01
x.xxx.± .0.003
Angles± 0.5°

Part Name: Top Plate
Project Name: SD T507
Drawn By: Clayton Carlson
Date: 2/15/20
Material: Aluminum
Scale: 0.400
Rev: 0
Sheet Number: 1 of 2
Part Number:



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x.xx.± .0.01
x.xxx.± .0.003
Angles± 0.5°

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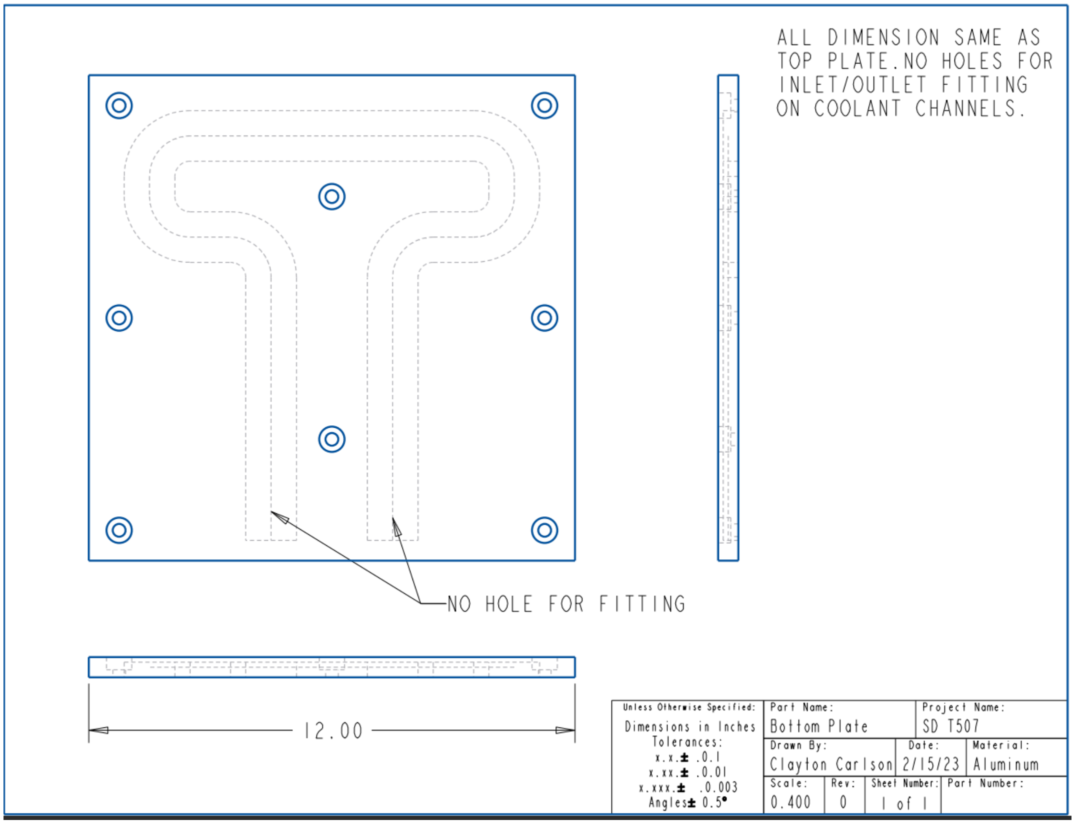
Drawn By: Clayton Carlson	Date: 2/15/23	Material: Aluminum	
Scale: 0.400	Rev: 0	Sheet Number: 1 of 1	Part Number:



ALL DIMENSION SAME AS
TOP PLATE.NO HOLES FOR
INLET/OUTLET FITTING
ON COOLANT CHANNELS.

Unless Otherwise Specified:
Dimensions in Inches
Tolerances:
x.x.± .0.1
x.xx.± .0.01
x.xxx.± .0.003
Angles± 0.5°

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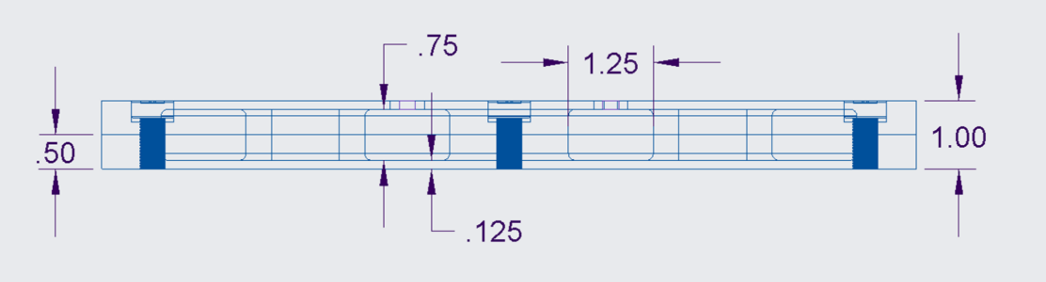
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