Battery Cell Testing Chamber

ECE 480 Senior Design Team 7

Sponsor:
XG Sciences

Authors:
Ali Behbehani
Matthew Marcantonio
Bradley Pasbjerg
Chengeng Qu
Executive Summary

The overall goal of this project was to create an environment that will be able to properly test and hold coin battery cells. Specifically, the team focused on implementation of a control system to the existing system already set up in the chamber. XG Sciences has provided the environmental chamber for modifications to be made. Main modifications to the chamber include the user interface, Microcontroller, the actuator, and the temperature sensor. The user interface in combination with the Microcontroller involved creating a custom printed circuit board (PCB) to connect the pins of the two devices. It also required the team to write C code to handle the interactions needed to make the Microcontroller communicate with the user as well as applying the correct power to the chamber based on our designed PID equation. In order to demonstrate the functionality of this project, the team developed a GUI interface with the Microcontroller to be able to visually track the temperature over time. The team was able to complete most of the objective, although it was unable to achieve full functionality with the cooling device. This project should be useful to XG Sciences in their labs for accurate testing to provide more concise data for processing.
Acknowledgement

Team 7 would like to acknowledge the help and cooperation of several individuals who contributed to the success of the project. Jeffry Narendra, the sponsor from XG Sciences, was of great help to get the project started. He was able to provide us with the environmental chamber as well as hardware to hold the battery cells but he also gave the team great advice to get the project going. Working with him has been a pleasure.

Brain Wright as well as Gregg Mulder have been a great help in developing our product. With developing our designed PCB’s as well as providing the necessary materials needed to complete our project. Roxanne Peacock has also been very helpful with dealing with part orders.

To all those listed above, we sincerely thank you for your cooperation. The success of the project had a lot to do with your invaluable help.
Contents

Executive Summary ............................................................................................................. 3
Acknowledgement ............................................................................................................. 4
Chapter 1: ......................................................................................................................... 7
  1.1 Introduction ............................................................................................................... 7
  1.2 Background ............................................................................................................... 7
  1.3 Objectives ................................................................................................................. 8
Chapter 2 .......................................................................................................................... 9
  2.1 Design for Six Sigma Tools ....................................................................................... 9
      Fast Diagram .............................................................................................................. 9
      Conceptual Design .................................................................................................... 11
      Business Model ........................................................................................................ 12
      Criteria for Success .................................................................................................. 13
  2.2 Budget ....................................................................................................................... 15
      Table 2: Cost Estimate .............................................................................................. 15
Chapter 3 ........................................................................................................................... 16
  3.1 Technical description of work performed ................................................................ 16
  3.2 Controlling power ................................................................................................... 16
  3.3 Zero Cross Detecting .............................................................................................. 17
  3.4 Timing the trigger pulse ......................................................................................... 18
  3.5 PID Algorithm ........................................................................................................ 18
  3.6 User Interface .......................................................................................................... 18
  3.7 Software implementation ....................................................................................... 19
  Design Issues .................................................................................................................. 19
      Interrupts .................................................................................................................... 19
      LCD display ............................................................................................................. 20
      PID tuning ................................................................................................................ 20
      GUI ............................................................................................................................ 20
Chapter 4 ........................................................................................................................... 22
  4.1 Control System User Interface ............................................................................... 22
  4.2 Sensor Calibration ................................................................................................. 23
4.3 Control System (Heating Part) ................................................................. 23
4.4 Thermoelectric Material ........................................................................ 25
4.5 Result for heating test (Thermoelectric): ................................................. 26
4.6 Why not Thermoelectric Material: ............................................................ 28

Chapter 5: ...................................................................................................... 29
5.1 Cost .......................................................................................................... 29
5.2 Schedule .................................................................................................... 30
5.3 Conclusion .................................................................................................. 31

Appendix 1: Technical Roles, Responsibilities, and Work Accomplished .... 32
    Chengeng Qu – Web Master .................................................................... 32
    Ali Behbehani – Presentation Prep .......................................................... 33
    Brad Pasbjerg – Document Prep ............................................................... 34
    Matthew Marcantonio - Team Manager .................................................... 35

Appendix 2: Literature and Website References .......................................... 36
    Literature and website references ............................................................ 36
    Programs Used ......................................................................................... 36
    Technical Datasheets ................................................................................ 36

Appendix 3: Detailed Technical Attachments ............................................. 37
    PID Control with Serial Interface ............................................................ 37
    Microchip PCB Pin Layout ..................................................................... 39
    Battery Cell Holder PCB Layout .............................................................. 40
    Final Schematic ....................................................................................... 41
Chapter 1:

1.1 Introduction

Testing is one of the more important processes in creating a successful product. Without a complete testing process, malfunctions might occur that will lead to a faulty product. Temperature testing is one of the most important issues in industry today. Without being able to control temperature with a high level of accuracy, temperature dependent devices will not be tested properly and variations in the temperature can be misread as defects in products. In order for these problems to be avoided, accuracy in testing must be ensured.

XG Sciences has taken interest in designing a system that would be able to create a system that will be able to create a reliable temperature as well as being able to log this information onto their computers for analysis later. The product XG Sciences makes are coin cell and pouch cell batteries. They are being innovative with the design of their batteries with size as well as functionality. These batteries are temperature sensitive and the researches in XG Sciences labs’ have noticed this problem. Testing for the devices at room temperature as well as high or low temperature limits are not being done accurately and they are interested in fixing this problem. Testing these batteries is done over a large period of time. The system will be running for weeks in order to deplete charge and recharge in order to get data on battery lifecycle and how the battery performs over time.

1.2 Background

There are many applications of environmental chambers that can do much more than our project calls for. Some are specially used for temperature, humidity, or even thermal shock and are large enough to stand in. These chambers are great for what they are used for, but they have too many features for the requirements and lacking in some areas. A chamber of varying temperatures from -65°C to 200°C is not needed, as well as other chambers with thermal shock capabilities. Our project is special because it fits the exact specification and needs that XG Sciences will need. XG is looking for a system that will be fully compatible with their labs. What team 7 will be able to achieve that a commercial industry will not is a digital feedback reading that the computers at XG can use for data logging as well as a custom chamber that will be able to accommodate XG’s coin cells for easy accessibility and testing.
1.3 Objectives

In this project the team is asked to create an environmental chamber that will be able to hold a constant temperature. The range of the chamber needs to span from -40°C to 85°C. The accuracy at all ranges needs to be with one degree of desired set point. The team will be making an interface to communicate to the system what the reference temperature will be, based on this reference the system will manage the two elements inside the chamber to be able to achieve the reference temperature at a steady state. Meanwhile, the chamber will also be communicating with the XG lab computers in order to track the temperature over time. The system will be implemented so that steady state operation will be achievable for days at a time. Another requirement is that the system should be able to reach stability at no more than two hours from starting up the system. Having a chamber with a long settling time is not desirable for testing situations.

The successfulness of the project will help the sponsor in testing their batteries efficiently and develop them to be better optimized. Power for portable devices is a hot research area nowadays, since portable devices are becoming more advanced and more power consuming. The system would help the sponsor in testing the current coin cell batteries, and discover the best way to build the battery. Moreover the sponsor is planning on manufacturing and testing some pouch battery cells in the future, and those are similar to the batteries that are currently used in cell phones. In this case the sponsor would be able to use the chamber to test such batteries as well as the coin cells. If the tests are successful, designs for a new solution to increase battery life will be soon to come.
Chapter 2

2.1 Design for Six Sigma Tools

Fast Diagram

To properly identify end goals and assist with overall development process, we used Six Sigma design tools. One of the most helpful tools we used was a fast diagram. The purpose of this exercise is to clearly define customer requirements and a way to implement them. The chart is set up that each block is connected to the answer of two questions; the block to the right is the answer of the question “How?”, and the block to the left is the answer to the question “Why?”. The main goal of our project is to control the temperature. This is done by either controlling the heating element or the cooling element. Both these elements are controlled through a PID controller which manages the voltage going to each device. The way the PID controller tells each element what to do is with a reference temperature and a temperature sensor by which it calculates the output voltage. These steps are illustrated in Figure 1.
Figure 1: Fast Diagram
Conceptual Design

After researching different control design applications that could be used for our design, a decision matrix was created to show the pros and cons of each technology. This matrix is based off of a 1 through 5 ranking system with 1 being the best and 5 being the worst, and corresponds to criteria that are required for our design. Some criteria that were seen as important in ranking each technology were stability, ease of implementation, reliability, ease of use, overall cost, and previous knowledge. The appropriate data was inputted into the matrix and totals were tallied up, which produced one viable option.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Criteria Importance</th>
<th>On-Off Control</th>
<th>Phase Modulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability</td>
<td>4</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Ease of Implementing with Existing System</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Reliability</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Overall Cost</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Previous Knowledge</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>36</strong></td>
<td><strong>23</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Table 1: Decision Matrix*
Business Model

This six sigma business model tool describes the rationale of how an organization creates, delivers, and captures value. It is a blue print design consisting of building blocks that would help establish milestones for our product, understanding competition, attracting investors, reducing cost, and attracting employees. It describes and innovates the business and its product. This useful tool can easily illustrate a complete picture of a business from an overall perspective. Figure 2 demonstrates the model for the environmental chamber.

![Figure 2: Business Model Canvas](image-url)
Criteria for Success

The main purpose of the environmental chamber is to provide a high accuracy temperature controlled area for testing. Therefore, the primary focus is whether our system can accurately control the temperature. A successful outcome consists of demonstrating that the temperature can be kept within a ±1°C. As a result, our design is focused on functionality rather than efficiency, with the assumption that future implementations of this project will perform necessary optimizations. Our design revolved around functionality instead of cost or size restrictions. A Risk Analysis Diagram was created and followed to make this prototype design achievable, as shown in figure 3 on the following page.
<table>
<thead>
<tr>
<th>Risk</th>
<th>Effect</th>
<th>Level of Impact (1, 3, 6)</th>
<th>Likelihood (1, 3, 6)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delayed PID Control Design</td>
<td>Delayed PID Testing</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Delayed Testing</td>
<td>Insufficient time to perfect design</td>
<td>3</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Unable to read temperature inside chamber</td>
<td>Unable to test/implement PID control</td>
<td>6</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Unable to control temperature within ±1°C range</td>
<td>Main objective not met</td>
<td>6</td>
<td>3</td>
<td>18</td>
</tr>
</tbody>
</table>

### Risk Analysis

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Risk Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Near Certainty</strong></td>
<td>5 10 15 20 25</td>
</tr>
<tr>
<td><strong>Highly Likely</strong></td>
<td>4 8 12 16 20</td>
</tr>
<tr>
<td><strong>Likely</strong></td>
<td>3 6 9 12 15</td>
</tr>
<tr>
<td><strong>Low Likelihood</strong></td>
<td>2 4 6 8 10</td>
</tr>
<tr>
<td><strong>Extremely Improbable</strong></td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td><strong>Severity / Impact</strong></td>
<td>Minimal Minor Major Serious Catastrophic</td>
</tr>
</tbody>
</table>

### Risk Value Legend

<table>
<thead>
<tr>
<th>Risk Value Legend</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Medium</td>
<td>&gt;5 &amp; &lt; 12</td>
</tr>
<tr>
<td>High</td>
<td>&gt;12</td>
</tr>
</tbody>
</table>
Figure 3: The figures above show the risk and likeliness of their occurrence during the design process

2.2 Budget

Design Team 7 was allocated $500 from the College of Engineering. Once the team had created an initial design and began selecting components, the estimated cost was well below the allocated budget. Table 2 displays all the components affecting the initial cost estimate. The computations required for implementing our designs could be done all with the microcontroller provided to us in our lab assignments. With all this in consideration, all of our costs were well below the allocated amount.

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcontroller (Explorer 16 Development Board)</td>
<td>$129.99</td>
</tr>
<tr>
<td>Temperature Sensors (Thermisters)</td>
<td>$5.89</td>
</tr>
<tr>
<td>Keypad</td>
<td>$13.52</td>
</tr>
<tr>
<td>Display Screen</td>
<td>On MC</td>
</tr>
<tr>
<td>Shelves</td>
<td>$40</td>
</tr>
<tr>
<td>Resistors/Capacitors</td>
<td>Free (ECE Shop)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$189.41</strong></td>
</tr>
</tbody>
</table>

Table 2: Cost Estimate
Chapter 3

3.1 Technical description of work performed

![Functional flowchart of microcontroller code](image)

**Figure 4: Functional flowchart of microcontroller code**

3.2 Controlling power

To effectively control the temperature within the chamber, power must be controlled as well. With the use of a triac, which is a multidirectional silicon controlled rectifier, the power of the chamber can be controlled through careful timing against the power wave. The gate of the triac low, it acts as an open circuit and blocks power to the load, or in our case the heating element. When the gate is pulsed, the triac becomes active and passes current to the load like a short circuit until the waveform signal returns to a zero state.

When the gate is pulsed, the source power is passed to the load as well as the gate pins. Since our microcontroller will be triggering when the pulse is fired, a way to
separate the microcontroller from the 120V wave that will be across the gate is needed. An MOC3020 optocoupler completely isolates the microcontroller pulse that triggers the triac from the hazardous voltages. This optocoupler itself contains a triac that is optically pulsed and uses the main AC power to pulse the high power triac controlling the load.

3.3 Zero Cross Detecting

To achieve proper phase modulation, the wall power amplitude must be monitored by the microcontroller. The microcontroller needs to know each time the amplitude crosses from 0V. The PIC microcontroller that is being used has an interrupt on change function, that can be triggered anytime the interrupt pin changes from high to low, or low to high. To properly interrupt the microcontroller when the wall power crosses 0V, a zero cross detector was used.

An analog comparator operational op-amp can be used as a zero cross detector, but because of the amplitude of the wall power another detector was used instead. A MOC3020 IC was used instead of a comparator. The MOC3020 has an infrared LED which can cutoff and saturate a photo-transistor within. The MOC3020 was wired so when the voltage was positive, the LED was forward biased cutting off the transistor and pulling the interrupt pin low to ground. When the voltage is negative, the internal LED is reversed biased which cuts of the internal transistor pulling the interrupt pin high. This effect can be seen in FIGURE 5. With the zero cross detector in place, the microcontroller can now monitor the wall line.

![Figure 5: Zero cross waveform vs sine wave input](image)
3.4 Timing the trigger pulse

As soon as a zero cross is detected by the MCU, an internal timer clock is set to 0. Because the timer is 8 bits and reset with every zero cross, we needed to time 256 counts of the timer to each half cycle of the wall power wave. A 1MHz oscillator scaled by 32 gave us 8.2ms for each half of the sine wave which at 60Hz is 8.3ms long. For the last 0.1ms if the power is triggered it would have no effect on the temperature of the chamber due to it being very close to 0V.

Depending on the power setting determined by a PID algorithm, the power delivered to the chamber can range from 0% to 100% in 0.4% intervals. The triac is triggered when the timer value exceeds the PID set point value. The triac returns to its cutoff state after every zero cross which also resets the internal timer, so the process is repeated as long as the microcontroller is running.

3.5 PID Algorithm

There are three main PID equations that could be utilized for control stability in the chamber. Types A and B are good starts, but their tuning parameters are mostly based around the set point of the temperature. Since our design goal calls for our sponsor to be able to enter any temperature from -40 to 85 degrees Celsius, a type C equation is the best choice. The PID type C equation has the tuning parameters based around previous temperature values instead of the set point error.

The PID setpoint is what will be compared with the timer value of the microcontroller, so it must be between 0 and 255. Simple if statements were used to set the value to 255 if it exceeded 255 and 0 if it was less than 0 as seen in Figure 2. Normally the higher the PID setpoint value, the more power applied to the system. The way the system applies power, the opposite is true. To fix this error, if the PID equation outputs 255 which would be full power, we want to subtract 255 by the PID output. This sets the operating point of the triac to 0, which is full power. A new PID setpoint is calculated every 10 seconds, or 600 zero crosses.

3.6 User Interface

The sponsor of our project wanted to be able to manually enter a temperature and be able to monitor the temperature over the length of the test. If after achieving steady state the temperature deviated beyond the desired tolerance, an alert should be logged letting the user know at what time the error occurred.

To allow the user to enter a temperature, a keypad was used with an LCD. As the microcontroller is powered up, after initializing all of the settings required, it enters a subroutine allowing the input of a temperature. The LCD has a prompt requesting that a
user enter a temperature, as the temperature is typed in, the LCD is used to verify the numbers entered are correct. Once the desired temperature is entered, pressing ‘#’ will call an atoi function that converts the entered character string to an integer and end the subroutine. After the temperature is entered the control system will run until it is disconnected from power, or until ‘*’ is held which will stop the system and will enter the set temperature routine again.

To monitor the temperature throughout the test, a serial to USB interface will allow data monitoring on an external computer. Once data logging is started, every 2 seconds the computer will call for the microcontroller to send the currently read temperature and plot it against the time of the test. Once the program has detected steady state, it will alert the user and begin watching for steady state deviations. If a deviation greater than 1 degree Celsius is detected it will create an alert with the current date and time. This allows the chamber to be run without constant monitoring and will let the user know if the temperature integrity has been compromised.

3.7 Software implementation

Every time the power source crosses 0, or a call to send temperature data to an external computer an interrupt service routine is called.

```c
#pragma code isr=0x08
#pragma interrupt isr
void isr(void)
{
    interrupt();
}
#pragma code
```

This interrupt routine when entered from a zero cross will reset the internal timer that determines the power applied to the chamber. If the routine is entered from a serial communications request, it will disable all other interrupts and send the requested data. These interrupts are the most important part of the software. Without them, the microcontroller would have no timing reference and would not be able to accurately apply power to the system.

Design Issues

Interrupts

The first issue big issue encountered this semester was the interrupt programming. Initially the interrupt was sporadic and didn’t fire after every zero cross. This interrupt problem caused stability problems with the power applied to the chamber and needed to be fixed. Since the zero cross detector was based around the amount of current flowing through an infrared LED, we lowered the resistor values from 10KΩ to
3.5KΩ to allow more current to pass. By increasing the maximum current through the LED, the zero cross interrupt became more responsive and fixed the sporadic behavior.

**LCD display**

The LCD used for this design would only function if it ASCII characters were sent for display. Since values displayed on the LCD were also critical parts of the code, a way to convert between the two needed to be found. Research done online gave us several functions that could be used to convert between integers and characters in our main C code. This allowed the microcontroller to keep every value as an integer or double value, but convert to a character string when a value was to be sent for display on the LCD.

**PID tuning**

Starting with values of one for each tuning parameter of the PID equation, it was observed that the PID didn’t function as intended. It functioned like an on/off controller which made the temperature oscillate outside of design specifications. Several trial runs of differing tuning parameters had to be tested until a semi functional PID system could be observed on the oscilloscope. Once the PID equation did not jump from one extreme to the other, we were able to tune it appropriately. Initially the unturned PID would overshoot by as much as 20˚C, but afterwards overshooting was around 7˚C and overall settling time was around 15 minutes.

**GUI**

The graphical user interface relied on values sent via the serial port of the microcontroller to plot the temperature. Getting the program to run on a computer that did not have Microsoft visual studios was a problem. Microsoft visual studios had a lot of critical files that were used to run the final executable that was compiled. The proper files needed to run the created GUI needed to be located and saved so the user could have the tools to use the program.

Getting the software to run on all computers was only one of the problems that were found while writing the interface. The temperature received from the microcontroller was not accurate at all. This throws off the deviation alert and provides inaccurate data that is collected throughout the test. A lot of debugging that included reading values that were sent to visual studios was done to find where the issue was occurring. The voltage which was converted to degrees Celsius was not an average value like what was found on the microcontroller. To fix this problem, the temperature that was being displayed on the LCD was sent instead of the voltage so both values were identical.
Chapter 4

4.1 Control System User Interface

Our control system’s user interface contains a 12-key keypad and a LCD display screen. The keypad enables user to input target temperature and the LCD screen will display both the target temperature and the current temperature. It can be seen that in Figure 6, a target temperature of 60°C is entered into the system. The current temperature of 57.8°C can be seen on the screen. (See figure 7).

Figure 6: LCD Display, Set Temperature

Figure 7: LCD Display, Current Temperature
4.2 Sensor Calibration

The sensor we used to build our closed loop feedback control system is TC1046 made by Microchip. It is a 3-pin temperature sensor that can output different voltage signals which depend on the temperature. We calibrated our sensor by using the thermometer Fluke 80T-150U Universal Temperature Probe. Here is the calibration result:

<table>
<thead>
<tr>
<th>Fluke 80T Temperature</th>
<th>Output Sensor Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>80°C</td>
<td>0.924V</td>
</tr>
<tr>
<td>40°C</td>
<td>0.674V</td>
</tr>
<tr>
<td>20°C</td>
<td>0.549V</td>
</tr>
</tbody>
</table>

From the result we can see that the voltage-temperature relationship is quite linear and the sensor works accurately. This linearity makes coding for the relationship between temperature and voltage very simple. Our estimated equation for the linearity of the sensor is as follows:

$$ V_{\text{Out}} = (6.25 \text{mV/}^\circ\text{C}) \times \text{Temperature (}^\circ\text{C}) + 424\text{mV} $$

4.3 Control System (Heating Part)

For our control system, we use Proportional-Integral-Derivative (PID) controller in series with Phase-Fired Controller to output control signal. Our control output signal will work directly with the AC voltage from wall outlet and it will be able to output voltage with different duty cycle. The interface between the control system and working circuit is the alternistor. Our system is tested in several steps.

Step 1. We use a hair dryer to heat up our sensor and monitor the output signal of our control system. The target temperature is set to be 60°C. With the increase of the temperature measured by the sensor, the pulse position of the control signal occurs sooner. The output control signal is shown together with wall outlet voltage signal in figure 8.
Figure 8: Triac signal with wall power

Step 2. We connect our control system to the environmental chamber and we heat up the sensor again. The voltage that feeds into the chamber’s working circuit is monitored and shown in figure 9.

Figure 9: Triac signal with output power

Step 3. We make our whole system working together. Sensor is positioned at the center of our battery holder and the battery holder is placed inside the chamber. The target temperature is set to be 60°C. We monitored the temperature shown on the LCD screen and recorded it by the GUI. The measurement is shown in figure 10. It can be seen that our control system works perfectly with a settling time of about 900 seconds.
4.4 Thermoelectric Material

The other option of building our environmental system is by using thermoelectric material. We do some test on a thermoelectric device and figured out that such material is not ideal for our project.

SP2402-01AB produced by Marlow industries is the thermoelectric module that is used. Under the room temperature of 20°C, the working side of the device can be as low as -90°C and as high as 130°C. A heat sink is required to dissipate heat. The device is shown in figure 11.
For a thermoelectric material, the side that is connected to the heat sink is chosen as the constant temperature side and the other side can be either colder or hotter than the constant temperature side depends on the voltage direction that feeds into the device. Both heating and cooling tests are executed. Test results can be found in figure 12.1 and 12.2.

4.5 Result for heating test (Thermoelectric):
Figure 12.1: Results for Heating test (Thermoelectric)

*Tested by Agilent E3630A power supply and Omega CN7800 temperature sensor

Figure 12.2: Results for Cooling test
4.6 Why not Thermoelectric Material:

Thermoelectric materials refer to materials that have strong thermoelectric effect. Thermoelectric effect refers to the fact that a voltage difference between two sides of the material will have a relationship with a temperature difference. Such kind of materials will be able to produce a temperature difference between its two sides by feeding in voltage. By controlling the voltage and keep one side of the material a constant temperature, the temperature of the other side of the material can be controlled.

However, there are several reasons that make thermoelectric material not ideal for our project. First of all, for the reason that the efficiency of thermoelectric material is too low, the main usage of thermoelectric material is to produce an extremely low temperature, for example -70°C on a surface. The space that can be controlled by the thermoelectric device is quite limited; it is only good for surface cooling. For our project, about fifty batteries are willing to be tested at the same time by using our system; as a result, we are trying to build an environmental system that can control a huge amount of space with a relatively narrow temperature range. Due to thermoelectric material’s low efficiency, it is clear that such material is not the best choice for our environmental system.

Even we disregard the low efficiency and use a lot of such material, it is still hard to build such a system. Considering the working principle of thermoelectric material, if the temperature of one side of the material needs to be controlled accurately, the temperature on the other side must stay constant all the time. This can be achieved by adding a big heat sink on the other side. The size of the heat sink with respect to the thermoelectric units can be seen in figure 11. This will take a lot of space and also cost a lot of money. When considering the fact that about fifty batteries are tested in our system, our system will be extremely huge in size, which makes it not applicable.

Another main reason for us to decide not to choose thermoelectric material is that thermoelectric material is not cost effective at all. For the reason that thermoelectric material is only good at surface heating and cooling, in order to accurately control the temperature, we will have to cover the battery on both top and bottom with the thermoelectric material. If we want to achieve a temperature below 0°C, multilayer structure is required. Taking all these into consideration, for only the thermoelectric material, it will cost at least 50 dollars for a single battery. There are also a lot of peripheral components, like heat sink, that needs to be added. It is able to say that the thermoelectric material based environmental system is not practical at all.
Chapter 5:

5.1 Cost

Over the course of this project, Design Team 7 was able to stay within the $500 budget given to them by the College of Engineering. With the help the ECE shop, the team was able to eliminate many items from their budget completely, mostly PCB fabrication as well as microcontrollers. Figure __ displays the final product cost for the chamber modifications.

<table>
<thead>
<tr>
<th>Expense</th>
<th>Qty.</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIC Microcontroller</td>
<td>1</td>
<td>Free (ECE SHOP)</td>
</tr>
<tr>
<td>Temperature Sensor</td>
<td>8</td>
<td>$5.90</td>
</tr>
<tr>
<td>Alternistor Triacs</td>
<td>6</td>
<td>$14.44</td>
</tr>
<tr>
<td>USB to Serial Adapter</td>
<td>1</td>
<td>$20.31</td>
</tr>
<tr>
<td>Metal Enclosure</td>
<td>1</td>
<td>Free (ECE SHOP)</td>
</tr>
<tr>
<td>LCD Display</td>
<td>1</td>
<td>Free (ECE SHOP)</td>
</tr>
<tr>
<td>Keypad</td>
<td>1</td>
<td>$13.52</td>
</tr>
<tr>
<td>1MHz, 10MHz Oscillator</td>
<td>2</td>
<td>Free (ECE SHOP)</td>
</tr>
<tr>
<td>Optocoupler</td>
<td>3</td>
<td>$1.23</td>
</tr>
<tr>
<td>Triac Trigger</td>
<td>2</td>
<td>$0.88</td>
</tr>
<tr>
<td>AC-DC Converter</td>
<td>1</td>
<td>Free (Extra DT5)</td>
</tr>
<tr>
<td>Shipping</td>
<td></td>
<td>$36.09</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>$92.37</strong></td>
</tr>
</tbody>
</table>
5.2 Schedule

Design Team 7 was unable to stay on schedule for the majority of the project. Time management and project management are two complex yet essential skills needed for successful completion of any project. DT7 was about to stay on schedule by utilizing the Gantt chart created early on in the semester until some unforeseen problems occurred that delayed our progress. Making up for shipping time as well as troubleshooting accounted for our failure to finish the project within the given semester. Allowing more time in our schedule to allow for our testing errors would have been the key to our success. Besides those few mistakes the semester was a very successful. Team management for the project was very well done, team members knew exactly what they were in charge of and when it was due with the help of our Gantt chart. We were able to complete a large portion of the project, with the control algorithm set in stone, as well as the heating and the battery cell holder. The Gantt chart used for this project can be found in Appendix 3.
5.3 Conclusion

Design Team 7 successfully designed, tested and verified functionality of the environmental heating chamber. Testing was done so in the design lab and XG Sciences’ criteria has been satisfied. DT7 has also created an easy to use interface as well an easy access testing mount for the coin battery cells. Due to time constraints that faced the team, the cooling portion of the chamber remains non-functional. With problems faced during our testing and troubleshooting, our scheduled plan has been delayed allowing no time in order to figure out the cooling valve functionality. With a functional actuator and a few more lines of code, our cooling system would have been achieved. While not every customer stipulation was satisfied, the completed design met all criterions except for a functioning cooling system. Much time was spent on the design and PCB fabrication in order to fit the design inside the chamber and interact from the outside.

In terms of completion, the heating portion and battery holder have been verified to design specifications. The temperature reading stabilizes to the reference with a ±0.5°C accuracy. In terms of accuracy, this is much more accuracy then what was expected for the project. For the settling time, the chamber reaches steady state temperature within 15 minutes from startup time, this is clearly much lower than the 2 hour settling time which was expected from us. In addition, DT7 was able to implement an interactive user interface that is able to take in a desired set point as well as being able to communicate through a micro USB interface to transfer temperature data to an external computer. Final cost of the project was under $100. Many of the components were provided by the ECE shop free of charge, which helped tremendously in reducing final cost. This value does not include the PCB fabrication in which ECE shop graciously provided us with.

DT5 was able to stay on schedule for the majority of the project duration. Minor challenges during the end of the semester had altered the schedule’s critical path. When tasks started to go off track, many team members worked long nights in the engineering building, strictly focusing on the project trying to get the team back on schedule. Experiences such as this and many other real world design issues this semester have given the team valuable experience. Each issue presented was thoroughly analyzed and systematically resolved. The members worked together in such ways that produced results, resolved problems and taught everyone important aspects of the engineering industry. For these reasons, design team 7 did have success in their project.
Appendix 1: Technical Roles, Responsibilities, and Work Accomplished

Chengeng Qu – Web Master

The technical impact Chengeng Qu had on his team was mostly about thermoelectric material. At the very beginning of the semester when the team was trying to do research on environmental control system design, the team figured out that it is not easy to implement both heating and cooling functions in a single system. The team was trying to find some method that can do both heating and cooling accurately inside one system. Then the team found out a new technology called thermoelectric material. It is a type of material that if one side of it is kept at constant temperature, the other side can be heating up and cooling down when we feed in different voltages.

Since it is a new technology and not a lot of information could be found related to this material, Chengeng was assigned the task to do some research on this material to see if it can work for our project. He searched the Internet and read a lot of papers related to the topic. He also contacted Dr. Tim Hogan, who is a professor in this field. Chengeng found out the working principle of this material and how it could be used in our daily life. The team’s technical lecture was also based on this topic.

Later Chengeng made a thermoelectric device and did some test on it. In order to reach the temperature range a multi-layer structure was chosen to make it powerful. In order to make the temperature stable, a big heat sink was also added. The whole device worked well and tests for both heating and cooling were implemented on that device.

However, after the team discussed the properties and applications together, the team figured out that this was not ideal for our project. For the reason that it has a low efficiency and it is only good for surface temperature control. Also it takes a lot of space and it costs too much.

Though the thermoelectric material is not used in our project, Chengeng learned a lot during the research, device build up and testing.
In choosing how to make a power supply for the control system the team had few choices. The microcontroller needs to be provided with 5V power supply that can handle few millie Amps. The choices are: design a power supply from scratch, using a power supply that has produces 9V or more with a 5V regulator circuit, or using a fully built power supply that could be used from inside the chamber. The major disadvantage of designing a power supply from scratch is that it would cost more than the other approaches, also, that power supply might have troubles in the future, since the team members are not experts in designing power supply and the sponsor wanted the whole system to be able to work for 24/7 and the testing might take 70 days. For that reason it is decided that designing a power supply from scratch might affect the final project expectations. The other, approach was somehow better, however, the power supply would be out of the chamber and would work independently from it, which would not be very user friendly for the sponsor. Also, it is unknown to the team that it would be safe to open the box of a power supply and use the materials and circuitry with the regulator circuit to form a modified power supply. Thus, user friendly and safety measurement and requirements were suggesting that this approach would not be very convincing. Hence, the third choice was the best among all the choices. The power supply that was chosen is the Artesyn NFN40-7607 power supply. This power supply takes in three inputs: AC line, AC neutral, and safety ground. Also, it can take either 240V or 120V and out puts +12V, +5V (two pins), and -5 volt, with two ground pins included. This power supply would have some extra options if the sponsor needed to develop some other circuitry inside it that might require power supply, thus, this power supply would be useful for such application.
Brad Pasbjerg – Document Prep

Brad Pasbjerg is an electrical engineer and therefore his technical role was primarily with hardware. As all members of the group were electrical engineering major, he has taken into account Microcontroller coding as well. He researched and designed the temperature feedback system for the control system. Brad started his work by selecting a temperature sensor and began constructing an Analog-to-Digital converter (ADC) setup for the PIC Microcontroller. Maximizing the accuracy of the system was the main concern in this part of the work. Many problems encountered during the implementation of the temperature sensor include the noise level from the reference voltage as well as the temperature signal itself. When dealing with these problems Brad eventually figured out to implemented a low-pass filter to admit the DC level reference as well as taking averaging in repeated ADC readings. The temperature sensor also needed to be properly calibrated to ensure it was displaying the correct temperature on the display. Calibrating the sensor involved taking data points of voltage at the output and comparing them to actual temperature readings from a Fluke 80T-150U Universal Temperature Probe, acquired from the ECE shop. In addition to designing the feedback sensor, Brad was also in charge of testing the environmental chamber for accuracy. After the chamber was about to produce a stable signal form the GUI, the multimeter temperature sensor was used in order to ensure the correct temperature was being displayed. Brad has also assisted Matt in programming as well by developing a Debouncer into the source code. Hardware contributions include the help of assembling and designing the PCB board to hold the PIC Microcontroller, assembly of the user interface, and setup of the enclosure.
Matthew Marcantonio - Team Manager

Matthew Marcantonio is an electrical engineer that was responsible for the programming of the entire design project. The source code was one of the most vital parts of the entire project. With the programming done by Matthew, the project could not function at all. The code Matt worked on implemented the PID controller, interfaced with the LCD and keypad, sent power to the environmental chamber, and interface with the GUI Interface. Creating a functional PID controller was difficult to implement with the code. After working out computational errors, the code was able to implement the feedback control loop properly. Having the PID equation was the first issue, another issue Matt has dealt with was the actuator of the chamber. Needing to have a controllable power source is absolutely necessary in order to control the temperature. Matt was able to research and configure the Phase-Fire controller. This actuator provided the ability for the Microcontroller’s PID equation to effectively tell how much power to give the heating coils.

Matt also focused on the GUI interface. With this interface the team was able to properly measure the temperature over time with a simple graph. This graph will enabled them to measure stability as well as fine tuning the PID equation to get the least possible overshoot in hopes to reach a very fast settling time. This GUI is essential for XG Sciences as well, as they will be using this graph in order to determine stability of the system. The graph will tell them when accurate data is happening or when the temperature has spiked due to opening chamber door or a malfunction in the chamber.

One of the important non-technical responsibilities Matt held was being the team manager. As a manager, he was in charge of time management for the team as well as keeping the team on task. Splitting up responsibilities, setting up team meetings, and communicating with the sponsor are all vital roles in making a team successful.
Appendix 2: Literature and Website References

Literature and website references

"Allen Bradley Logix5550 Independent PID equation":
http://bestune.50megs.com/typeABC.htm

Programs Used
MPLAB:
Microsoft Virtual Studios
http://www.microsoft.com/visualstudio/en-us

Technical Datasheets
“High Percision Temperature-to-Voltage Converter”:
Keypad Datasheet
Optocoupler Datasheet
Optoisi 400vDRM Triac out
Triac Datasheet
Appendix 3: Detailed Technical Attachments

PID Control with Serial Interface

```c
void main ()
{
    OpenUSART (USART_TX_INT_OFF & USART_RX_INT_ON &
    USART_ASYNCH_MODE & USART_EIGHT_BIT &
    USART_CONT_RX & USART_BRGH_LOW, 63);
    RCONbits.IPEN = 1; // Enable interrupt priority */
    IPR1bits.RCIP = 1; /* Make receive interrupt high priority */
    INTCONbits.GIEH = 1; /* Enable all high priority interrupts */
    PORTD = 0;
    TRISH = 0xFF;
    TRISO = 0x00;
    PORTBbits.KBI0 = 1;
    TRISC = 0xF0;
    PORTBbits.RA6 = 0;
    INTCONbits.TMR0IF = 0;
    LCD_Init(); // set up LCD for 4-wire bus, etc.
    LCD_PutCmd ( CLEAR_DISP ); // clear screen
    LCD_SetPosition ( LINE_1 + 0 );
    LCD_Putstring(string);
    enter_temp();
    INTCONbits.TMR0IF = 0;
    LCD_Init();
    LCD_PutCmd ( CLEAR_DISP );
    LCD_SetPosition ( LINE_1 + 0 );
    LCD_Putstring(string);
    enter_temp();
    INTCONbits.TMR0IF = 0;
    LCD_Init();
    LCD_PutCmd ( CLEAR_DISP );
    LCD_SetPosition ( LINE_1 + 0 );
    LCD_Putstring(string);
    enter_temp();
    INTCONbits.TMR0IF = 0;
    LCD_Init();
    LCD_PutCmd ( CLEAR_DISP );
    LCD_SetPosition ( LINE_1 + 0 );
    LCD_Putstring(string);
    enter_temp();
    INTCONbits.TMR0IF = 0;
    LCD_Init();
    LCD_PutCmd ( CLEAR_DISP );
    LCD_SetPosition ( LINE_1 + 0 );
    LCD_Putstring(string);
    enter_temp();
    INTCONbits.TMR0IF = 0;
    LCD_Init();
    LCD_PutCmd ( CLEAR_DISP );
    LCD_SetPosition ( LINE_1 + 0 );
    LCD_Putstring(string);
    enter_temp();
    INTCONbits.TMR0IF = 0;

    // Pulse fires sporadically at 5V but for some reason
    // Works fine at 4.64V WTP is going on??? setpoint
    while(1)
    {
        INTCONbits.GIEH = 1;
        //pulse fires sporadically at 5V but for some reason
        // Works fine at 4.64V WTP is going on??? setpoint
        if((255-TMR0L) <= setpoint && a == 0)
        {
            T0CONbits.TMR0ON = 0;
            TRIAC = 1;
            delay2();
            TRIAC = 0;
            a = 1;
            b = b+1;
            c = c+1;
            TMR0L = 0x00;
        }
        if(b>=30)
        {
            T0CONbits.TMR0ON = 0;
            INTCONbits.RBIE = 0;
            SetChanADC(ADC_CHO);
            LCD_TempAvg();
            //LCD_PutInt();
            PID();
            INTCONbits.RBIE = 1;
            b = 0;
        }
        if(c>=1200)
        {
            T0CONbits.TMR0ON = 0;
            //LCD_PutInt();
            c = 0;
        }
        PORTCbits.RC3 = 0;
        while((!PORTCbits.RC4))
        {
            PORTCbits.RC3 = 1;
            enter_temp();
        }
    }
}
```

// stop
Battery Cell Holder
Final Schematic