Automatic Bake-Out Assembly (A.B.O.A.)

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Abstract

The purpose of the summer project between June 5, 2011 and July 29, 2011 was to create a fully automatic bake out assembly that would not only automatically bake out an aparatus using ten separate heat tape/thermocouple pairs while comparing temperatures of heat zones, but would also be portable and easily modified. This was to enhance the current methods where variacs are controlled manually, which could lead to possible equipment damage and inefficient systems due to user error.

Introduction

A bake out is a heating process which, without the use of chemicals, cleanses an apparatus and reduces the out gassing rate (or rate of dissolved, trapped, absorbed, or frozen gas in a material being released ("Dictionary.com")) of the volume that is to be placed under vacuum. The apparatus to be baked out is already cleansed before it is shipped to the lab and is also shipped in a clean environment. However, a bake out removes the majority of the particles on the molecular level in the apparatus that cannot be removed by conventional cleaning methods. A bake out accomplishes this by using heat while pumping on the volume to accelerate the out gassing rate that would naturally occur when the system is under vacuum alone. The bake out commences until the molecular out gassing rate is at a sufficiently low and stabilized rate. ("Alias Aerospace")

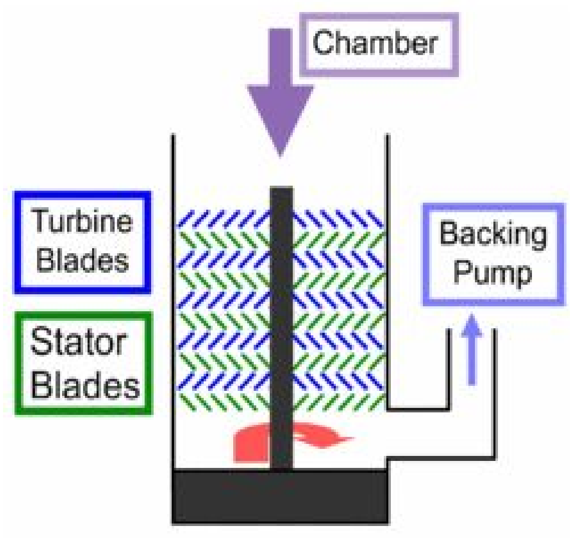
A manually controlled bake out can last from a few days to a couple weeks with constant monitoring. Automating the system would allow for a timely bake out with the ability to adjust the ramping speed, soaking period, maximum temperature, and maximum deviation of temperature between heat zones. Low deviation of temperatures between heat zones is critical because if heat zone temperatures vary too greatly, one heat zone could thermally expand more than another causing stress on welds, valves, and other parts. Without human error, low deviation is more likely. The Automatic Bake Out Assembly (ABOA) must also be easy to use and should cycle through a bake out faster than a manual cycle. The ABOA should have the ability to continue the cycle over a weekend or another period where there is no staff on hand.

The goal of this summers project was to organize the assembly in which the automated bake out components would be housed, transported, and utilized. The automated bake out system would heat ten elements, heat the elements at a given rate, and check the pressure inside of the element.

The Bake Out Process

The chamber to be processed is evacuated with a 2-stage system consisting of a turbo molecular pump, which exhausts into a backing pump (Figure 1). If no large vacuum leaks are present, a mass spectrometer called a residual gas analyzer (RGA) can be turned on when the pressure is approximately 10^{-6} torr. The RGA is an extremely sensitive device which detects leaks at the level of the final pressure approximately 10^{-9} torr, before the chamber is baked.

Figure 1: Diagram of a 2-stage vacuum pump system



Leak Testing

An RGA leak test is performed using a tank of helium gas and a "wand" that can adjust helium flow. The "wand" is moved around the seams, flanges, fittings, and welds of a volume under vacuum to check if the RGA picks up any sign of leaks. A leak would be indicated if there is an increase in the signal given by the RGA. The RGA has a "leak check mode" that looks specifically at a desired amu (in this case, helium).

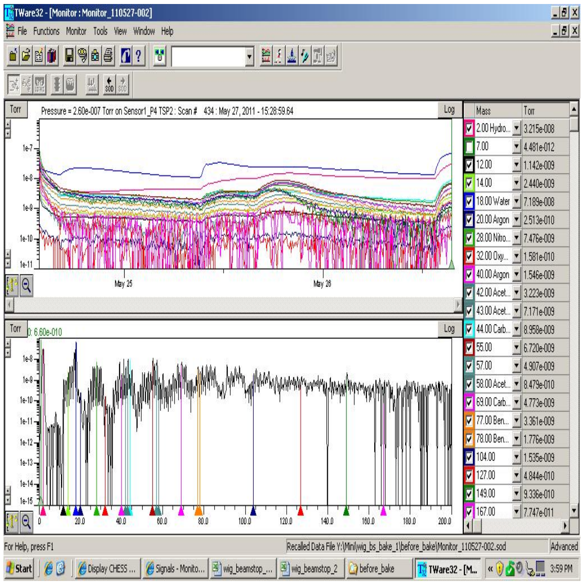
External leaks, caused by mechanical problems such as bad welds or gasket seals, are not repaired by the bakeout and need to be addressed beforehand. Once the chamber is determined to be leak free, an initial partial pressure vs. molecular mass scan is taken. The total pressure before the bake is usually greater then 1^{-7} torr using a turbo pump which initially turn on at about 1mT.

Residual Gas Analyzer Scan

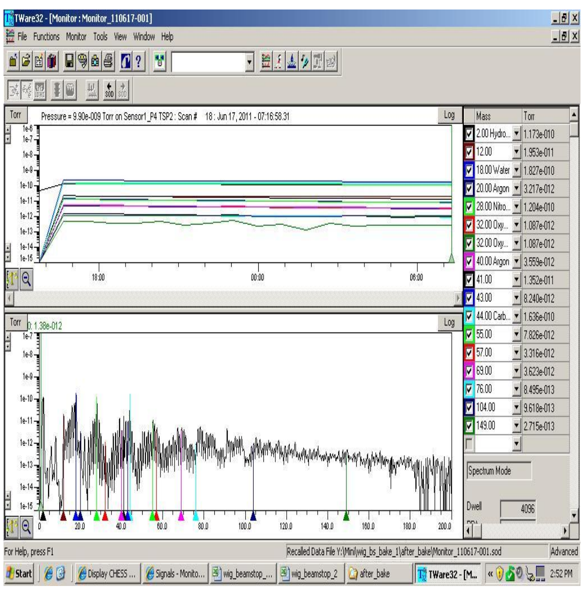
The RGA scan is performed to see the molecular composition of the volume prior to the bake out. In this instance, the RGA is placed into a mode that can detect a range of atomic masses. *(Note: RGA scans are always performed at room temperature).*

An RGA is a mass spectrometer that measures the chemical composition of a gas. To do this, an RGA ionizes a gas to create a charge. In an RGA scan the gas being detected moves through an ionizer which ionizes the gas using an electron beam. A mass analyzer then sorts the ions with respect to atomic mass by an RF quadropole that only allows certain ions to pass through based upon its mass-to-charge ratio for a given frequency. The ions are then detected by either a Faraday Cup or an electron multiplier. ("Thomas Net")

RGA scans are critical to the bake out processes at Cornell High Energy Synchrotron Source (CHESS). Since CHESS uses high intensity x-rays for their experiments, it is critical to have clean parts with low outgassing rates that would not interfere with the x-rays and cause intensity loss. An example of an RGA scan (Figure 2) represents a graph of an RGA scan on a Wiggler Beam Stop before and after a bakeout. Comparing the two images in Figure 2 shows a sufficient decrease in partial pressures of the ions and compounds in the system, especially with large masses.



(a) RGA scan before bake out



(b) RGA scan after bake out

Figure 2: Graph of an RGA scan of a Wiggler Beam Stop before and after a bake out. The top graphs in each image represents Partial Pressure (torr) vs. Time (hr.) and the bottom graphs in each image represents Partial Pressure (torr) vs. Atomic Mass Units (amu)

Wrapping

Thermocouples are attached to the apparatus to read the temperature of each heat zone. The apparatus is wrapped in thick aluminum foil, heat tapes are wrapped around the apparatus (with each heat tape coinciding with a thermocouple), and wrapped again in aluminum foil *(Note: Aluminum foil is used to insulate the apparatus and thermocouples and also transfers heat evenly from the tapes to the object. The stainless steel of the apparatus is a poor conductor while aluminum is an exceptionally good one).*

/subsubsection*The Bake Out

The bake out begins when the apparatus is "ramped up" to a desired set point temperature via manually controlled variacs that control voltage to the heat tapes *(Note: variacs are only used when a manual bake out is taking place).* If previous data is available, it can be used to configure the rate at which the apparatus is heated by using small setpoints. If there is no available data then an educated guess must be used. Heated nitrogen gas is passed through the apparatus to heat the inside components of the volume. Once the apparatus is at the desired set point temperature, it is left at that temperature for an extended period of time in what as known as a "soaking" period.

Finally, the apparatus is ramped down to room temperature using educated guesses derived from the ramp up settings. *Note: It is OK for the heat zones to cool at a different rate than when ramped up as long as each zone cools at a similar rate without too much difference between each zone. The ramp-up rate is also used as a guide to ensure the apparatus does not cool too rapidly and cause damage to the components.* Once at room temperature, another RGA scan is performed and compared to the first. The second RGA scan should show a lower out gassing rate than what was observed initially based off of the pressure in the volume. Also, out gassing of specific elements/compounds should decrease. The apparatus is then prepared for storage or is put into use.

A Need for Automation

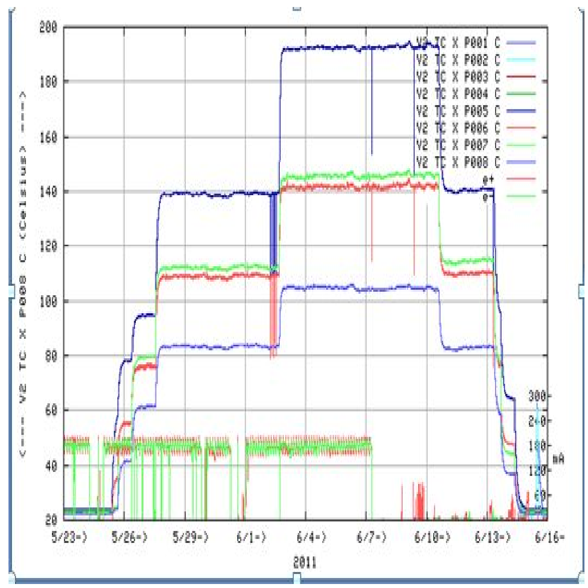
As one can see, the manually controlled method is both time consuming and difficult to control. Figure 3 represents a manual bake out and the time span in which it took place. Observing that the bake out process took almost a month to complete it is obvious that a bake out takes a large time commitment from the user.

Figure 4 (b) shows how the pressure in a system varies during a bake out. The steep spikes in the graph represent a rise in pressure when the temperature is ramped up. This occurs because of thermal expansion. The ABOA will eventually compensate for this and hold heat zones until the pressure is at a desired point.

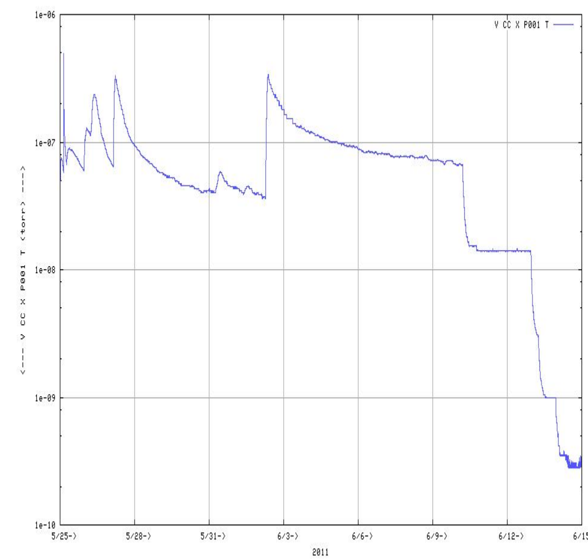
Figure 4 represents a period in the bake out over a weekend where no changes were performed. An automated bake out could continue control within this time span. Comparing this time span to Figure 3, it is easy to see how much time would be saved with an automated system where no user input is needed during the bake out.

Figure 5 shows an example of a prototype test that was performed to test the iTools logic program with a two channel automated system. Although the system does not react to pressure, the goal is for a ten channel system to show similar results. *(Note: adding pressure to the system might cause a "stepping" to the temperature when observed closely, but the overall ramp rate over an extended period of time would be constant).*

It can be seen that an automated system not only allows for a much quicker bake out process, but also allows for an unfamiliar user to perform a bake out and choose a specific max temperature, ramp speed, and soak time. Also, in a manual bake out, an operator uses mostly educated guesses to deter-



(a) Temperature (^oC) vs. Time (hr.) graph of bake out



(b) Pressure (torr) vs. Time (hr.) graph of bake out

Figure 3:

Figure 4: Zoomed in graph of manual bake out between 5/29/11 and 6/1/11

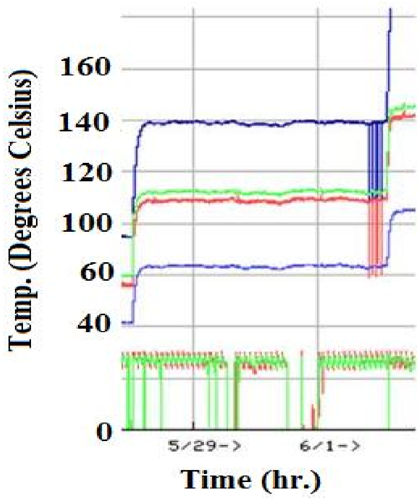
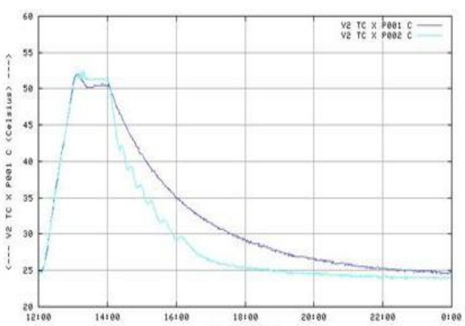


Figure 5: Graph of two channel prototype over a 12 hour period



mine how much power to send to the heat tapes. This allows for a high probablility of error. It is difficult to establish a constant ramping rate and to ensure that each heat channel ramps evenly. The automated system would make these constraints easier to satisfy and would decrease the amount of error and damage a user could cause.

The ABOA Project

Materials

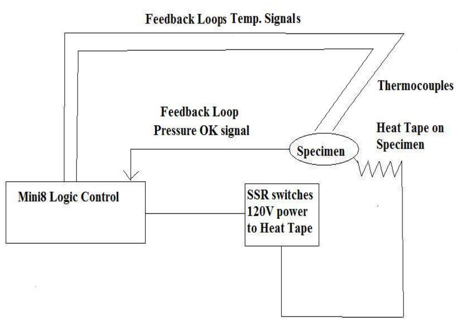
- 10- Solid State Relays
- 10- Heat Sinks
- 12- Thermocouple Wires/Ports
- 1- 47”x19”x26” Equipment Rack
- 5- 3 Prong 15 Amp Comp. Plug Power In
- 10- 3 Prong 15 Amp Power Out
- 1- Eurotherm Mini8 Multiloop Temperature Controller
- 1- Vacuum Gauge Controller
- 1- Moxa Ethernet Converter
- 1- Ethernet Box
- 10- GFCI Circuit Breakers
- 1- 120V Rack Mount Power Strip
- 1- Cooling Fan
- 1- 4 Amp Fuse
- 4- Custom Made Rack Panels (1/8” Aluminum)
- 1- 24V Din-Rail Mounted Power Supply

Automated Bake Out Logic System

A logic program was designed with iTools to control the temperature. The logic was designed to not allow for a change in temperature with respect to distance (dT/ds) greater than a set amount. Similarly, the logic was designed to not allow for a change in temperature with respect to time (dT/dt) greater than a set amount. The logic would heat up all loops evenly and at the same rate. Also, if the pressure exceeds a given set point, the heating loops would be held at the controllers current setpoint until the pressure is allowed to drop back to the desired set point.

The Eurotherm Mini8 was selected for the temperature controller due to its ability to be programmed to suit the project's requirements and conditions. Figure 6 represents a visual diagram in which the logic is interpreted. In this "circuit" the thermocouples attached to the specimen conducts a voltage with respect to the temperature of the specimen. The Mini8 reads the temperature from the thermocouples and then activates the SSRs which switches 120V AC power to the heat tapes.

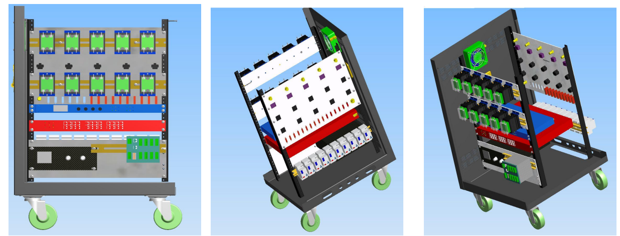
Figure 6: Layout of how the Logic Heating System operates



Project Progression

Space Diagrams

To receive a visual of how everything would be placed in the portable cabinet a space diagram was created in Autodesk Inventor. Inventor allowed for the creation of a 3D visual representation of the project with the ability to create, destroy, and manipulate parts to the users liking in order to fit all of the materials into the cabinet in a safe and convenient manner. Figure 7, respectively, shows a front, rear, and isometric Inventor representation of the finished product.



(a) Front View (b) Rear View (c) Isometric View

Figure 7: Front (a), Rear (b) and Isometric (c) views of Inventor Space Diagram

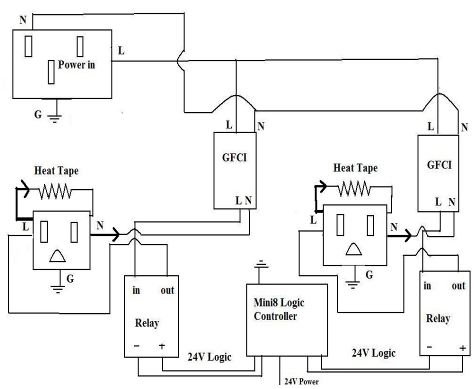
Design/Order Needed Parts

Once a space diagram was created and a basic layout was agreed upon, a design process was implemented to create certain panels that were not readily available. The Solid State Relays were too heavy to be held by Din-Rail alone. Therefore, panels were made to support them. The Gauge Controller was a panel mounted component, but the Mini8 Logic Controller was mounted to Din-Rail. For convenience, and to save space, a plate was made to mount both of these components next to each other. Finally, the power supplies, thermocouple ports, and the 4 Amp Fuse had to be mounted to a panel for safety and convenience purposes. Therefore, a single panel was created for all of these components.

Each plate was designed using Inventor in the original space diagram to fit into the cabinet. The Inventor file that represented each panel was converted into an Inventor Drawing File (.idw) and then plotted for a machinist to create.

Wiring for the apparatus had to be done as well. Each wire was cut, stripped, and soldered to fit the given circuit. Twelve gauge wire was used for each cable that was switching 120V. This included the cables going from the Power In to the GFCI and the cables from the GFCI to the Solid State Relays and to the Power Outs. The 24V signal cables going from the Mini8 to the Solid State Relays were 24 gauge twisted-pair wire(Figure 8). *(This circuit was repeated five times for the final product.)* Also, twelve thermocouple wires had to be stripped and assembled into plug ports that were mounted to a panel and wired to the Mini8. Ten GFCI Breakers, each rated for 10 Amps, needed to be ordered.

Figure 8: Circuit diagram for a two-channel relay system



Preparation of Cabinet for Assembly

The cabinet needed to have a cooling fan mounted to it so that the components, especially the Solid State Relays (SSRs), would not overheat inside the cabinet. The cooling fan was mounted near the top of the assembly on the vents and close to the Solid State Relays to expel the hot air that rose to the top of the cabinet. Four 17/32" holes were drilled so that the fan could be mounted using four 6-32 screws, nuts and washers. It was found that the factory vents in the cabinet were not sufficient enough to expel the air that the cooling fan was trying to displace. Therefore, six 1/4" holes were drilled around the circumference of the fan path to allow for more air flow.

Figure 9: 6 1/4" drilled out holes to allow for better air flow from cooling fan

Also, the cabinet needed two 17/32" holes on its chassis for the grounds on the circuitry. These were each drilled on opposite sides of the cabinet and were mounted with lock bolts and washers. The paint on the cabinet's surface near the ground bolts was scraped off to ensure a reliable electrical connection.

Assembly

Once all of the parts were set up, received from the machine shop, or received from companies, the ABOA was ready to be assembled in a pattern resembling Figure 7 and wired with respect to Figure 8. *Note: Parts in the machine shop were broken and on order. Therefore, the assembly of the A.B.O.A. was put on hold for roughly one work week.*

A panel mounted power strip was mounted to the racks of the cabinet on the rear side. The SSRs were mounted to the Heat sinks with a thin layer of silicon thermal paste in between for sufficient heat transfer. The SSR/Heat Sink assemblies were then mounted to the Din-Rails, which mounted to the custom support panels. The support panels mounted to the racks of the cabinet. The GFCI Breakers were mounted to Din-Rail and the rack. The SSRs and GFCIs were wired together, and all of the plugs, fuses, and thermocouples were mounted into the custom panel for the power. The connectors for the plugs and fuses were soldered and shrink tubed. The wires were routed, soldered, and assembled and the ground wires were mounted to the chassis of the cabinet using the pre-drilled holes. Cable mounts, zip ties, and wire loom were then used to organize and route the circuitry (Figure 10)

(a) Wireloom around wires

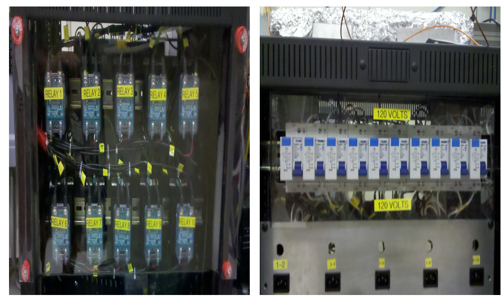
(b) Zip ties to hold wires together

Figure 10: Examples of cable management

The panel supporting the Gauge Controller and the Mini8 Logic Controller was mounted to the rack of the cabinet. The Ethernet converter and Ethernet box were mounted to the panels of the cabinet and connected up to one another and the Mini8 via Cat5e cable. All components needing external power were connected up to the rack-mounted power strip

Safety Features

To ensure safe use of this assembly, the apparatus was designed with certain safety features. The Ground Fault Circuit Interupter breakers (GFCIs), not only cut power if the circuit is shorted or is sending more power than desired, but also allows for a manual shut off for each relay. The GFCIs, din-rail power supply for the Mini8 Logic Controller, and Heat Sinks were all protected by a Flexan Polycarbonate shield so that users have a low risk of accidently touching terminals that are exposed. (Figure 11)



(a) Heat Sink cover

(b) GFCI cover

(c) Power cover

Figure 11: Flexan Safety Covers

Every wire connection has shrink tubing applied to it so, once again, the user can not touch any wires that may be exposed by unforeseen circumstances.

As an extra precaution, all high voltage locations have been labeled according to the amount of voltage each area is switching so that the user is aware of where the high voltage is located.

Results

Figure 12 shows the completed bake out assembly before the system was powered up for the first time.

(a) Front View (b) Rear View

Figure 12: Front and Rear views of finished product

On 6/29/2011, the ABOA was powered up for the first time with nightlights in the Power Out Plugs to ensure the heat tapes would function properly. Three specimens, a hollow aluminum pipe, a solid stainless steel pipe, and an aluminum block, were all mounted with thermocouples, heat tapes, and wrapped with aluminum foil. The logic was set to ramp to a max temperature of 60^oC with a ramp rate of 30^oC/hr and a maximum temperature deviation of 5^oC. The Mini8 and heat tape channels 1 through 3 were connected up to mains power. Once the Mini8 showed that is was receiving power, the iTools logic program was started. The logic program successfully activated the relays which switched power to the nightlights and heat tapes.

Channels 2 and 3 switched at an expected rate while channel 1 switched power at an increasing rate until full power was reached. This occured because the thermocouple from the power panel to the object in channel 1 was wired incorrectly. Once this error was corrected, the ABOA was powered up and all three channels switched power at an expected rate.

The bake out was monitored periodically and it was found that all three channels ramped up, soaked for an hour, and ramped down successfully with error. A temperature deviation of 10^oC as opposed to 5^oC was the only found problem with the cycle.

Conclusion

The purpose of this summers project was to design, fabricate, wire, and assemble an automatic bake out apparatus that was safe, would be able to protect equipment, be mobile, and easy to use. The automated system should heat the elements evenly at a set rate, watch pressure, and complete a full bake out cycle faster than a manual method.

Once the ABOA was fully assembled and passed all safety inspections channels 1 through 3 were connected to power and tested with nightlights. Once it was clear that the circuitry was working and the heat tapes were connected up to the system, a bake out up to 60^oC with a ramp rate of 30^oC per two hours and a maximum temperature deviation of 5^oC commenced.

The bake out ramped up, soaked for an hour, and ramped down with very few errors. In the upcoming weeks more channels will be tested and a pressure monitoring system will be integrated.

Project Problems

During the design of the ABOA a few problems arose. Wires for the circuitry were found to be cut at insufficient lengths and were cumbersome, some power outlets melted during the soldering process, and the power plate was too thick to hold the power outlets properly.

If this project were repeated it would be advisable to wait until the components were assembled in the ABOA before cutting the wire for the circuitry to ensure sufficient lengths. 14 guage wire would also be suggested to use for the 120V wiring as opposed to 12 guage. The 12 guage wire proved to be cumbersome and needed more heat to solder and thus allowed for the power outlets to melt during the soldering process. The power outlets had tabs to hold them in the power plate. The plugs were originally designed to fit in a much thinner sheet metal than the 1/8" that was used. It would be suggested to use screw mounted outlets next time instead of panel-clip power outlets.

References

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