Electrostatic Precipitator

IPFW MET Senior Design Spring 2015

Sponsored by Graphite Customs LLC.

Members: Casey Spurgeon
Dan Cummings
Chandler Tracey

4/27/2015

Table of Contents

Introduction

This paper will outline the design and process for building an electrostatic precipitator (ESP). This is presented as an approach to containing graphite powder while machining. It will cover the purpose, the design calculations, the fabrication, test results, overall cost, and the conclusions we discovered in the process.

Background & Problem Statement

Graphite Customs LLC is a local company in Fort Wayne that specializes in precision machined graphite molds for glass blowing and glass arts. They have been working with local companies to design, refine, and produce graphite molds for just over a year. All the molds produced are done on a CNC machine and hand finished.

Figure 1 – Graphite Customs LLC mold
http://graphitecustoms.com/?page_id=225

The process of machining graphite creates a lot of dust particles that coat the entire facility in a layer of graphite. The company has given us the task of creating a system to contain the unwanted graphite powder. Before we began, the current system used a cyclonic separator and dust collecting vacuum, but particles were still getting loose and the vacuum was getting overwhelmed with the amount of dust created.

Solution

To overcome the issue of excessive graphite dust, we decided to design and build and electrostatic precipitator. An electrostatic precipitator (ESP) is a device that, in the simplest of terms, filters particles by forcing a gas through a negatively charged apparatus, and then the particles are attracted to positively charged collection plates. ESPs are used typically in industrial settings where a large amount of unwanted particles need to be removed from the environment; such as a coal burning electrical plant. ESPs can also be used in smaller applications; such as smoke eaters in bars, or home air cleaners.

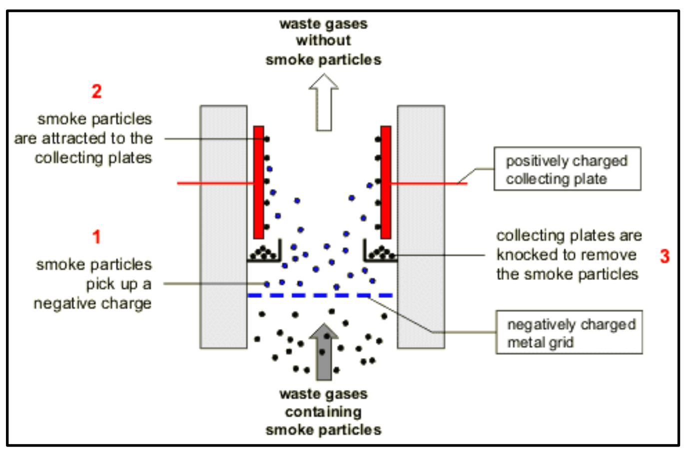

Figure 2 – ESP Diagram
http://www.bbc.co.uk/staticarchive

Design Parameters

- Greater than 95% containment of particles
- Price of under $250
- Conscientious of ESP size

Electrostatic Precipitator

As mentioned previously an ESP is a device that separates particles in a gas, in this case air. The air will be passed forced through a negatively charged metal mesh, and then pass by positively charged collection plates. The graphite particles will become ionized when passed through the mesh, and be attracted to the collection plate; where they will remain until the electric field is turned off. The inner workings of the ESP will be revealed in more detail in the section to follow.

Figure 3 - Industrial ESP
http://i01.i.aliimg.com/photo/v0/280530729/ESP_Electrostatic_Precipitator_Industrial_Air_Filter_for.jpg

Components

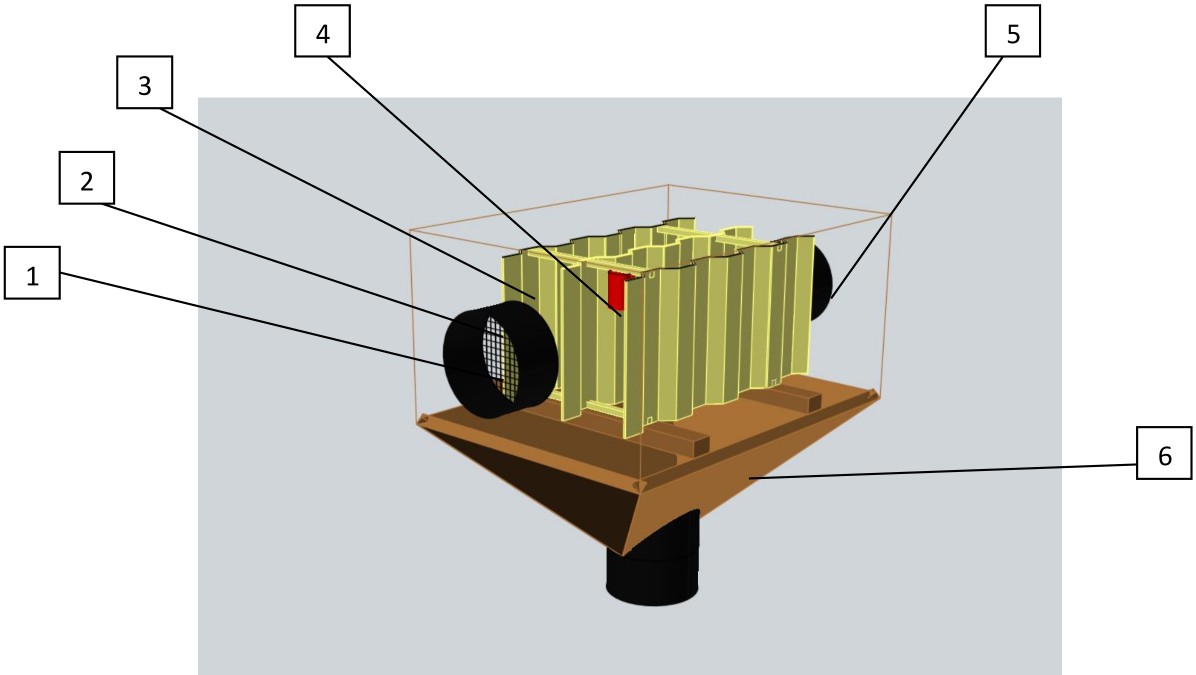

Figure 4 - Component diagram

1. Negatively charged aluminum mesh.
   - This part of the ESP will ionize the particles in the air upon being passed through. We chose aluminum for its ability to conduct electricity, as well as the cost of the material compared to other strong electric conductors.
2. Plastic inlet connection for 4" vacuum hose.
   - The plastic inlets were designed at 4" to match up with the company's existing dust collection vacuum, and plastic was an easy choice as we did not want this component to conduct electricity.
3. Positively charged aluminum collection plates
   - These plates will be positively charged, as the ionized graphite particles pass by, they will be attracted to the plates and stick.
4. On/Off shaker to clean plates without removing
   - This will be attached to the housing, when the electric field is powered down; the shaker can be switched on to knock the graphite loose off the plates.
5. Outlet connection
   - Identical to the inlet connection, it will be connected to the dust collection vacuum.
6. Funnel for collected graphite
   - Once the graphite is shaken loose from the collection plates, this funnel will guide the particles to a collection bin.
7. High voltage power supply (not pictured)
   - This will provide the voltage needed to create an electric field between the negatively charged mesh, and the positively charged collection plates.

Science behind an Electrostatic Precipitator

Electrostatic precipitators work by forcing gas, in our case by a vacuum, through an electrode with a highly negative charge. The negatively charged particles in the gas are attracted to another electrode with a highly positive charge.

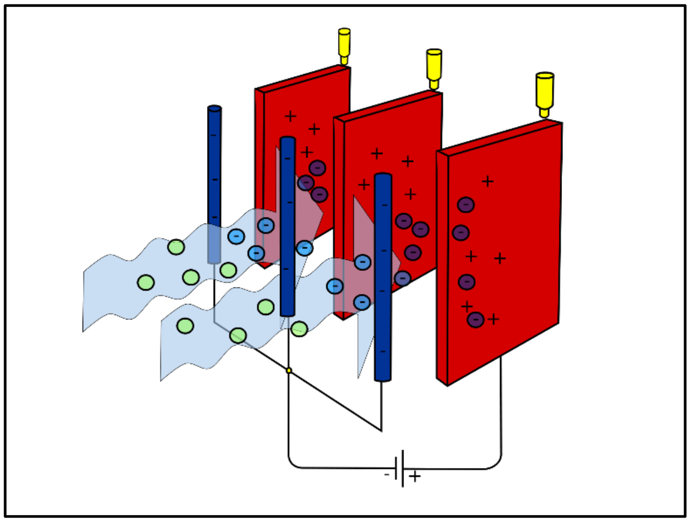

Figure 5 – Corona diagram http://upload.wikimedia.org/wikipedia/commons/thumb/5/52/Electrostatic_precipitator.svg/2000px-Electrostatic_precipitator.svg.png

A high voltage is required to produce a corona discharge which is caused by ionization of the graphite particles surrounded by a conductor. The corona power is a result from the current and voltage applied, current is required for charging the particles and voltage is required to produce an electric field.

Proof of Concept

To prove the theory behind our ESP, we hooked up our power supply to a small ESP constructed out of a small PVC pipe, aluminum mesh, and aluminum foil. To test this, we hooked up the negative lead to the mesh, and the positive lead to the aluminum foil. Once connected, we lit a small incense on fire that produced a constant flow of smoke upwards. When the power supply was turned on, the flow of smoke was immediately stopped and the smoke particles began collecting on the aluminum foil.

Figure 8 – Assembled mini ESP

Figure 7 – Negatively charged mesh

Figure 6 – Positively charged aluminum foil

Design Calculations

In our initial calculations, we were still learning the science behind ESPs and mistakenly used an incorrect variable, drift velocity of the collection plates instead of the graphite particles. So we have two sets of calculations, both with the correct variables. The first set of calculations represents the efficiency of our first design, and the other represents the efficiency of the revised design.

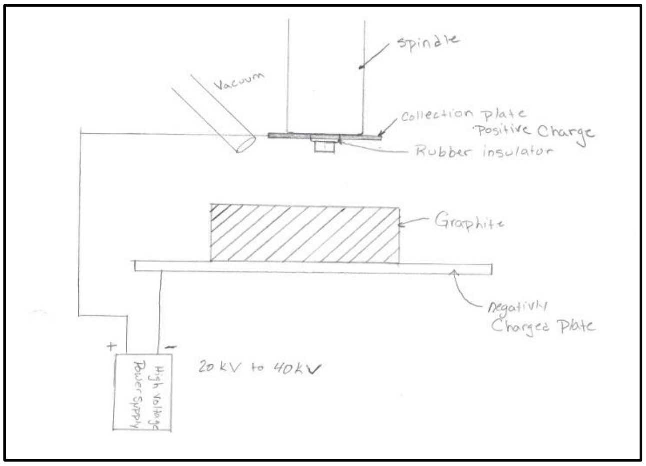

Figure 10 - Rough sketch

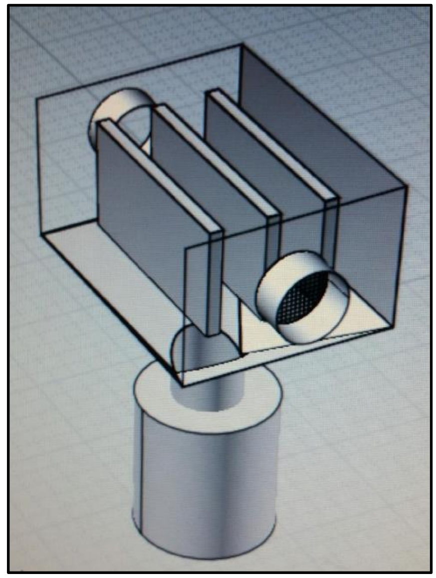

Figure 9 - Initial design drawing

Initial design

Calculating drift velocity of the machined graphite particles:

Derived from the current formula I = nAve

V, drift velocity = I/nAe

I = current, .006 A

n = free electron density for graphite (a semi-conductor), n = 6 x 10^{16} m^3

A = .37 m^2

e = elementary charge (electric charge carried by a single proton, or the negation of the electric charge carried by a single electron), 1.6 x 10^{-19} C

Q = flow rate, .73m^3/s

$$V = \frac{I}{nAe}$$

$$V = \frac{.006\ A}{(6*10^{16}\ m^3)(.37\ m^2)(1.6*10^{-19}\ C)} = 1.68\ m/s$$

Collection efficiency:

$$R = 1 - e^{\left(-AV_d / Q\right)}$$

$R = 1 - e^{\left(\frac{-.37\, m^2 * 1.68\, m/s}{.73\, m^3/s}\right)}$ = .573 = 57.3% collection efficiency

Revised design

V, drift velocity = I/nAe

I = current, .03 A

n = free electron density for graphite (a semi-conductor), n = 6 x 10^16 m^3

A = 1.02 m^2

e = elementary charge (electric charge carried by a single proton, or the negation of the electric charge carried by a single electron), 1.6 x 10^{-19} C

Q = flow rate, .73 m^3/s

V = $\frac{I}{nAe}$

V = $\frac{.03\, A}{(6*10^{16}\, m^3)(1.02\, m^2)(1.6*10^{-19}\, C)}$ = 3.06 m/s

Collection efficiency:

$$R = 1 - e^{\left(-AV_d / Q\right)}$$

$R = 1 - e^{\left(\frac{-1.02\, m^2 * 3.06\, m/s}{.73\, m^3/s}\right)}$ = .985 = 98.5% collection efficiency

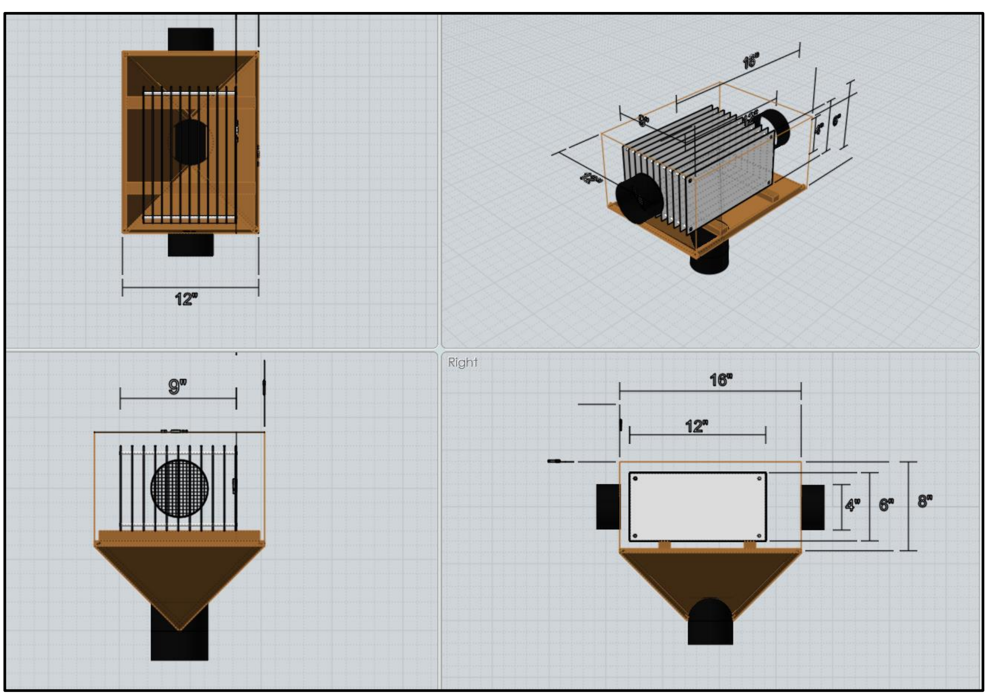

Figure 11 - Revised ESP design

Fabrication Procedure

Housing

-The housing for the ESP was constructed out of veneered plywood using glue to hold the structure together. The bottom was cut using a CNC machine for precision, and the rest was cut with a table saw. The inlet and outlet were press fit into the housing. The inside of the housing was insulated with Flex Seal™ rubber spray to prevent the wood from burning due to the powerful electric field being generated.

Figure 13 - Assembled housing

Figure 12 - Funnel to collection bin

Ionizing mesh and Collection plate

-The aluminum mesh was cut to fit the inlet and fastened using electrical tape to insulate the mesh from arching with the housing. The aluminum collection plates were purchased to size at 6”x12” and fastened together using threaded rod and nuts to hold the plates together. Our calculations showed that 11 plates would give us 98.5% efficiency.

Collection bin

-The collection bin was constructed out of a 5 gallon bucket fitted with a 4.5” O.D. PVC pipe that fits into the opening at the bottom of the ESP housing.

Figure 14 - Collection plates and collection bin

Figure 15 - Neon sign transformer

Power source

-The high voltage power supply we used is an old neon sign transformer. The transformer puts out 12,000 volts and 30mA. This provided plenty of power to create the electrical field needed.

Overall cost

The price shown represents what it cost to build the unit of our final design. This total cost came in under the budget set by the initial design specifications at the beginning of the project. The major cost saver of the project was the high voltage power supply which was an old neon sign transformer found at an industrial equipment resale facility. Without the saving on the high voltage power supply, the total cost of the project could have easily been around or over our initial budget.

Component	Price
Wood	$30.00
Inlet/outlet	$14.67
Aluminum plates	$34.21
Aluminum mesh	$4.28
Threaded rod	$4.88
HV Power supply	$20.00
5 Gallon bucket	$2.14
PVC pipe	donated
Wire	$8.00
Hardware	$3.57
Flex Seal	$13.29
Total Cost	$135.04

Table 1 - Total cost

Test results and comparison to initial performance specs.

- Greater than 95% containment of particles
  - The theoretical calculation of our design showed that we should have no problem collecting at an efficiency of 95%. Our original testing procedure was going to be to take a piece of graphite, weigh it, then machine it, and weigh it again. The amount of weight lost in machining should all be accounted for in the weight collected in the collection bin. However, this was difficult to test. The difference in weight was too small to accurately measure with a readily available scale. Instead, we compared samples of filter material placed over the outlet of the ESP and simply used a visual test. One piece of filter material was from running the machine program without powering on the ESP,

and the other was with powering on the ESP. Just visually it was easy to tell how much better the ESP collected than just using the dust collection vacuum on its own. More important than any measurable testing, it was clear that this system worked better than what was previously being used by Graphite Customs LLC.

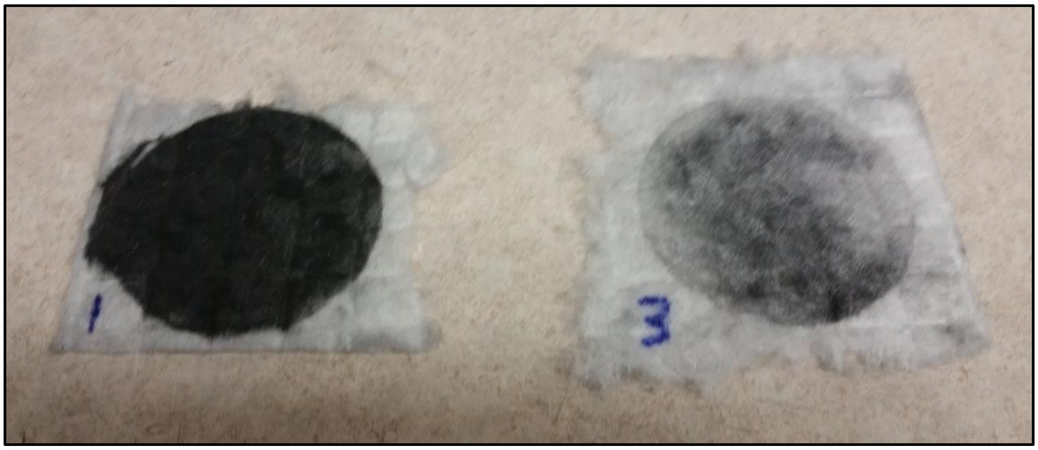

Figure 16 - Test filter samples. Test piece 1 is without the ESP, test piece 3 is with the ESP.

- Price of under $250
  - As stated earlier, the price of our final design came in well under budget. Primarily due to the power supply we were able to find at a low price.

- Conscientious of ESP size
  - With no actual design specs. pertaining to size, it was more of just making something that could be handled by a single operator and not take up too much real estate in the shop. We accomplished this in making a final assembly that came in standing at 36” tall, 19.5” long, and a width of 12”. The whole unit can easily be picked up by one operator and roughly weighs 60 pounds with the high voltage power supply attached.

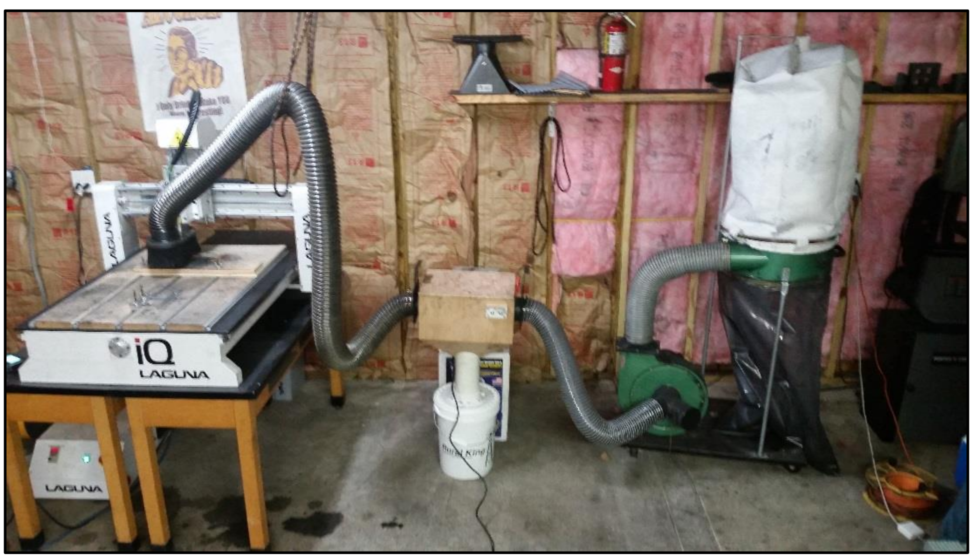

Figure 17 - Entire assembly with CNC and vacuum

Conclusion

In finishing the project, we are pleased with the results. The parameters were to contain greater than 95% of the graphite particles, build the device for under $250, and be conscientious of the build size. We were successful in meeting the parameters. We also understand we were fortunate to come in under budget with the finding of the high voltage power supply at the equipment resale. The whole process was a great example of applied design. We were able to learn a lot when it comes to facing adversity in design errors and were able to recover and complete a working electrostatic precipitator.

Our recommendations for anyone looking to build an electrostatic precipitator would be to triple check all design calculations, and give yourself plenty of time to find a high voltage power supply to assure a low cost in the final price of the build.

Gantt Chart

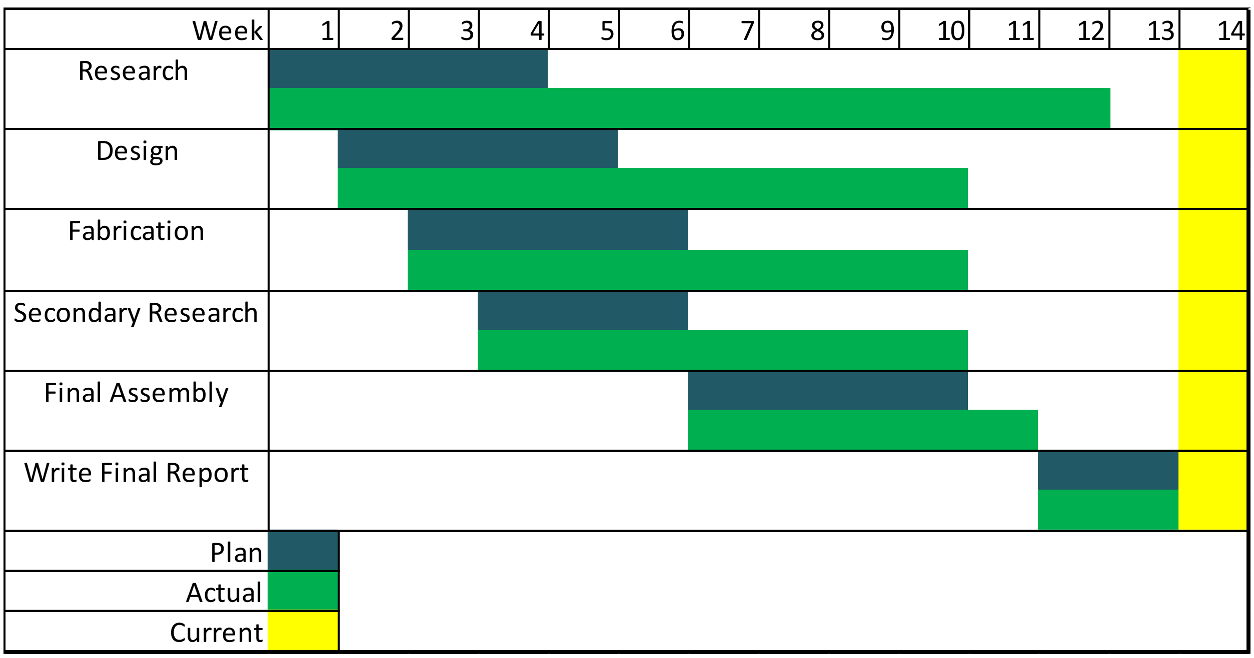

Figure 18 - Gantt Chart

Bibliography

- *ESP Design Review*. Neundorfer. Web. 26 Feb. 2015. https://www.neundorfer.com/FileUploads/CMSFiles/ESP%20DesignReview[0].pdf
- Griffiths, David (1999). Introduction to Electrodynamics (3 ed.). Upper Saddle River, NJ: Prentice-Hall. p. 289.
- http://230nsc1.phy-astr.gsu.edu/hbase/electric/ohmmic.html Ohm's Law, Microscopic View, retrieved Feb 14, 2009
- Raymond, Jimmy. *Electrostatic Precipitator Design Calculator*. AJ Design Software. 2011. Web. 24 Feb. 2015.http://www.ajdesigner.com/phpprecipitator/electrostatic_precipitator_equation_collection_efficiency.php
- Slade, Bill. *Experiments with a simple electrostatic precipitator.* Skynet. 8 Oct. 2004. Web. 5 Jan. 2015. http://users.skynet.be/BillsPage/Precip2.pdf.
- About Us. Graphite Customs. Web. 23 Apr. 2015. http://graphitecustoms.com/