S&G Metal Fab Battery Tray

By

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Abstract

This report was written for the design of a battery tray and manufacturing process for S&G Metal Fab. The manufacturing steps of how to process the sheet metal to create the product are defined and documented in this report. This project began with constraints given by S&G and were all accomplished using coursework knowledge obtained as a manufacturing engineer student at Cal Poly San Luis Obispo. This report mainly covers parameters regarding the cutting, bending and, deforming of sheet metal to acquire the desired shapes and sizes. It also analyzes the costs that are associated with these processes and material.

5052 h32 aluminum sheet metal with a thickness of .090" was used to create a battery tray that would be adequate for off- road use. This process was created to not exceed a production cost of $40 and not exceed a production time of two hours. All documentation of operation, part drawings, and routing sheets can be found in the report.

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Introduction

This Project was taken on to help aid a local company in the design of a battery tray and the manufacturing process to build the battery tray. This Battery tray will be a new product for the company and this report will be used for determining the viability and feasibility of selling the item online for profit. The documentation involved in the project will also be used as guidelines for further products to be released in the future. S&G currently creates custom parts and would like to use the battery tray as a stepping stone to begin manufacturing products in larger quantities.

To properly mount a vehicles battery for off road use the battery must be restricted from motion in all directions. For this reason a rigid tray that restricts movement in all directions will be designed and manufactured. The following is a list of the main deliverables that will be completed by the end of this project:

- Design of Battery Tray
- Design of process to manufacture battery tray
- Proper documentation of process (operation sheet and routing sheets)
- Detailed part drawings
- Analyze cost based on direct material and direct labor

All of these objectives will be achieved using skills learned during the course of the curricula for the Bachelor's Degree of Manufacturing engineering, as well as research done on similar projects that has previously been published.

Various tools were used throughout this project. Computer aided drawing (CAD) software were used to create models of the part and detailed drawings. Word processing was used to create all documents. Also various metal working tools were used, such as a TIG welder, metal brake, and dimple die and CNC plasma cutter. The end item created for this project will be will be presented to S&G Metal Fab for further analysis. This prototype will then be used to create a final product to add to the current off-road motorsports line of products.

Background

The battery in a vehicle is a vital component to its operation. It is responsible for starting the engine and in newer models it is necessary to keep the modern electronics running. For this reason it is imperative that the battery be securely mounted and connected at all times. In most vehicles the battery comes mounted with a simple metal strap that is bolted to the frame. This approach provides limitations for the battery along the vertical axis, keeping it from bouncing up and down. This is efficient for typical everyday driving, however in the off road world this approach is very inefficient.

During off- roading vehicles are exposed to heavy vibration, extreme angles, and extreme shock. For this reason OEM parts are not sufficient enough to keep the battery in place. The battery needs to be restricted from movement in all directions. For this reason many off-road companies produce battery trays that provide mounting support in all directions. S&G metal Fab; a local custom off-road shop would also like to begin producing such products. This product will be sold online with independent demand, and will also be used on custom builds as dependent demand to the entire build.

Currently there are a number of products available, some are vehicle specific, and others are general purpose. The following are a few companies that currently produce a type of battery tray intended for off road use:

- **Trail gear**

(www.trail-gear.com)

- **Camburg Motorsports**

(www.camburg.com)

- **Wild Horses four Wheel Drive**

(www.wildhorses4x4.com)

These products will all be studied and evaluated when designing the battery tray for S&G Metal Fab. The goal is to design and manufacture a high quality battery tray that conforms to S&G Metal Fab's standards and maintains a certain level of visual aesthetics.

This is project is important in the growth of S&G Metal Fab's company. As the company begins to thrive they would like to expand their company offerings and enter new industry markets. The capabilities and knowledge of metal working and welding will allow them to be successful in the off- road market. In order to get a handle on the success of initiating such a product this report will attempt to estimate possible processes and costs. In essence this report will be used to decide the viability and feasibility of entering the off-road market for S&G.

Literature Review

In order to effectively and efficiently design an off-road battery tray research and review must be done in the area of interest. For this project research has been done in areas of battery properties and limitations, design for manufacture/ assembly, material selection, metal working, and material joining methods. By doing this research greater insight to key design methods and features have been obtained. Methods and decision making

Battery Properties and Limitations

The battery being used for this application is a valve-regulated lead-acid battery (VRLA). This is a sealed lead-acid battery that is rechargeable and commonly used in most vehicles. Specifically an absorbed glass mat (AGM) VRLA battery will be used. The benefits of an AGM battery are that it has nearly twice the life of a conventional battery and improved reliability and flexibility. (*PR Newswire*. (2001, Apr 05).   The AGM battery is designed so that the electrolyte in the battery is absorbed in a glass mat between lead plates. This allows for low maintenance of the battery and flexibility of mounting the battery. Because the electrolyte is absorbed in the glass mat, it is less likely to spill out of the sealed case.

For this reason the battery can be mounted in almost any position other than inverted.

Although the battery's fluid is absorbed in the glass mat material it still has a potential to spill out of the sealed plastic casing. The fluid that comes out of a battery is most commonly referred to as battery acid and is very corrosive. This electrolyte is usually made up of about 35% sulfuric acid (H_2SO_4). Sulfuric acid is highly corrosive and can extreme damage to other

materials such as metals, rubbers, and plastics; all common materials used in components found in vehicles. This is why it is so important to have the battery securely mounted so that it will not become dis-oriented. During operation the battery will also heat up and reach a certain maximum temperature specified by the manufacturer, property of the battery will be explored and addressed in the material selection portion of the literature review.

Design for Manufacturing and Assembly

The approach of design for manufacturing and assembly will be used during the design stages of the battery tray. This approach to product design systematically includes considerations of manufacturability and assemblability in the design. (Mikell P. Groover (2010).)This method includes following general principles and guidelines during the design stages. One of the main principles of DFMA is the concurrent design principle. This principle states that the design of the product as well as design for manufacturing should be done concurrently so that no major reworking must take place. Table 40.5 from the text ***Fundamentals of Modern Manufacturing*** list the guidelines that will be used and followed:

TABLE 40.5 General principles and guidelines in design for manufacturing and assembly.
Minimize number of components. Assembly costs are reduced. The final product is more reliable because there are fewer connections. Disassembly for maintenance and field service is easier. Reduced part count usually means automation is easier to implement. Work-in-process is reduced, and there are fewer inventory control problems. Fewer parts need to be purchased, which reduces ordering costs.
Use standard commercially available components. Design time and effort are reduced. Design of custom-engineered components is avoided. There are fewer part numbers. Inventory control is facilitated. Quantity discounts may be possible.
Use common parts across product lines. There is an opportunity to apply group technology (Section 39.5). Implementation of manufacturing cells may be possible. Quantity discounts may be possible.
Design for ease of part fabrication. Net shape and near net shape processes may be feasible. Part geometry is simplified, and unnecessary features are avoided. Unnecessary surface finish requirements should be avoided; otherwise, additional processing may be needed.
Design parts with tolerances that are within process capability. Tolerances tighter than the process capability (Section 42.2) should be avoided; otherwise, additional processing or sortation will be required. Bilateral tolerances should be specified.
Design the product to be foolproof during assembly. Assembly should be unambiguous. Components should be designed so they can be assembled only one way. Special geometric features must sometimes be added to components to achieve foolproof assembly.
Minimize use of flexible components. Flexible components include parts made of rubber, belts, gaskets, cables, etc. Flexible components are generally more difficult to handle and assemble.
Design for ease of assembly. Part features such as chamfers and tapers should be designed on mating parts. Design the assembly using base parts to which other components are added. The assembly should be designed so that components are added from one direction, usually vertically. Threaded fasteners (screws, bolts, nuts) should be avoided where possible, especially when automated assembly is used; instead, fast assembly techniques such as snap fits and adhesive bonding should be employed. The number of distinct fasteners should be minimized.
Use modular design. Each subassembly should consist of five to fifteen parts. Maintenance and repair are facilitated. Automated and manual assembly are implemented more readily. Inventory requirements are reduced. Final assembly time is minimized.
Shape parts and products for ease of packaging. The product should be designed so that standard packaging cartons can be used, which are compatible with automated packaging equipment. Shipment to customer is facilitated.
Eliminate or reduce adjustment required. Adjustments are time-consuming in assembly. Designing adjustments into the product means more opportunities for out-of-adjustment conditions to arise.

Compiled from [1], [2], [9].

(Mikell P. Groover (2010).)

By using DFMA principles a product will be created that should be efficiently and easily created. These are much desired criteria in the manufacturing market when thinking about utilization of resources and maximization of profits.

Material Selection

The Odyssey battery used in this application is from the Extreme Racing line of batteries rated to operate in the range of -40 degrees F to 176 degrees F. (Enersys (2010)) Knowing this information it would be wise to select a material with a melting temperature above the upper limit. For this reason 5052 h32 aluminum sheet metal will be used to create the battery tray

because of its melting temperature of 2600-2800 degrees F. Other options were explored such as steel sheet metal and plastic resins. Plastic was eliminated because of the relative lower melting temperature and due to the limitations of the S&G Metal Fab's resources. Steel was initially considered because of its similar strength to aluminum, yet relative cheap costs. It was ultimately eliminated due to two factors. (1) Steel is very corrosive compared to aluminum and (2) because aluminum does not rust it requires no finishing steps, such as paint or powder coating. There are obviously many other materials that may be used, but many factors must be accounted for. Materials such as carbon fiber and fiberglass could have been selected; again due to shop limitations and DFMA guidelines these were eliminated. However, these options will not be ignored in the future workings of new designs to the product created.

Metalworking

When working with metal it is important to understand processes used and tolerances that can be achieved. Because the battery tray doesn't need to have extremely high tolerances this area is not extremely important, but it is important to know that the bends in the sheet metal must be accounted for when establishing the initial size compared to the final product. When sheet metal is bent perfect 90 degree angles cannot be achieved. A curved radius that results in a 90 degree angle is achieved and this curved radius results in an excess amount of material. Many articles are available that try to mathematically model the spring back of bent metal and allowance for bent metal, but again due to the loose tolerances necessary these methods have only been explored, and will not be utilized during the design or manufacture of the battery tray. However a very simple equation will be presented along with a chart to compensate for bend

allowances. The following equation and chart shall be used when calculating the desired lengths for the final product:

Bend Deduction Chart

$$BendDeduction = 2 * (\tan\left(\frac{B<}{2}\right) \cdot (IR + MT)) - \frac{\pi}{180} \cdot B< \cdot (IR + K \cdot MT)$$

	8 Gauge	10 Gauge	12 Gauge	14 Gauge	16 Gauge	18 Gauge	20 Gauge	22 Gauge	24 Gauge
	K factor 0.33	K factor 0.33	K factor 0.33	K factor 0.33	K factor 0.33	K factor 0.33	K factor 0.33	K factor 0.33	K factor 0.33
	MT / IR	MT / IR	MT / IR	MT / IR	MT / IR	MT / IR	MT / IR	MT / IR	MT / IR
	0.163 / 0.210	0.135 / 0.164	0.105 / 0.118	0.075 / 0.105	0.060 / 0.092	0.048 / 0.066	0.036 / 0.020	0.030 / 0.020	0.024 / 0.020
Angle	Deduction	Deduction	Deduction	Deduction	Deduction	Deduction	Deduction	Deduction	Deduction
10	0.0193	0.0159	0.0123	0.0088	0.0071	0.0056	0.0042	0.0035	0.0028
15	0.0292	0.0240	0.0187	0.0134	0.0107	0.0086	0.0064	0.0053	0.0043
20	0.0396	0.0325	0.0253	0.0181	0.0145	0.0116	0.0086	0.0072	0.0057
25	0.0504	0.0414	0.0321	0.0231	0.0186	0.0148	0.0109	0.0091	0.0073
30	0.0619	0.0509	0.0394	0.0284	0.0228	0.0182	0.0133	0.0111	0.0089
35	0.0742	0.0609	0.0472	0.0341	0.0275	0.0218	0.0158	0.0132	0.0106
40	0.0876	0.0718	0.0556	0.0403	0.0325	0.0257	0.0185	0.0155	0.0125
45	0.1020	0.0836	0.0646	0.0470	0.0380	0.0300	0.0213	0.0179	0.0145
50	0.1179	0.0965	0.0745	0.0544	0.0441	0.0348	0.0243	0.0205	0.0166
55	0.1354	0.1107	0.0853	0.0626	0.0508	0.0400	0.0276	0.0233	0.0189
60	0.1548	0.1265	0.0973	0.0717	0.0583	0.0458	0.0312	0.0263	0.0215
65	0.1763	0.1439	0.1106	0.0819	0.0667	0.0522	0.0351	0.0297	0.0243
70	0.2005	0.1634	0.1254	0.0933	0.0761	0.0595	0.0394	0.0334	0.0274
75	0.2276	0.1853	0.1420	0.1061	0.0867	0.0676	0.0441	0.0375	0.0309
80	0.2581	0.2100	0.1606	0.1205	0.0987	0.0768	0.0493	0.0420	0.0347
85	0.2928	0.2379	0.1817	0.1370	0.1124	0.0872	0.0552	0.0471	0.0391
90	0.3322	0.2697	0.2056	0.1557	0.1281	0.0991	0.0618	0.0529	0.0440
95	0.3774	0.3060	0.2329	0.1772	0.1460	0.1128	0.0692	0.0594	0.0496
100	0.4293	0.3477	0.2644	0.2020	0.1668	0.1285	0.0776	0.0668	0.0560
105	0.4895	0.3961	0.3007	0.2308	0.1909	0.1467	0.0873	0.0753	0.0633
110	0.5598	0.4525	0.3430	0.2643	0.2191	0.1680	0.0985	0.0852	0.0718
115	0.6425	0.5188	0.3927	0.3039	0.2523	0.1931	0.1116	0.0967	0.0818
120	0.7407	0.5975	0.4516	0.3509	0.2918	0.2229	0.1269	0.1103	0.0937
125	0.8587	0.6921	0.5224	0.4075	0.3394	0.2588	0.1453	0.1265	0.1078
130	1.0026	0.8074	0.6086	0.4765	0.3975	0.3025	0.1675	0.1462	0.1250
135	1.1809	0.9502	0.7154	0.5621	0.4696	0.3568	0.1948	0.1705	0.1462
140	1.4067	1.1309	0.8504	0.6705	0.5610	0.4255	0.2293	0.2012	0.1731
145	1.7003	1.3658	1.0258	0.8116	0.6800	0.5148	0.2739	0.2409	0.2079
150	2.0957	1.6822	1.2620	1.0017	0.8404	0.6352	0.3338	0.2942	0.2546
155	2.6540	2.1287	1.5952	1.2701	1.0669	0.8052	0.4181	0.3693	0.3205
160	3.4973	2.8030	2.0983	1.6757	1.4094	1.0621	0.5450	0.4825	0.4199
165	4.9106	3.9331	2.9413	2.3557	1.9836	1.4927	0.7572	0.6718	0.5864
170	7.7486	6.2020	4.6336	3.7212	3.1369	2.3575	1.1827	1.0515	0.9203

Where:

MT= Metal Thickness

K= Modulus of Elasticity

IR= Inside Radius

Another metal working technique that will be considered during the production of the battery tray is a process known as dimpling of the sheet metal. This process may give the final product some added strength, but in the case of the battery tray it is mostly for appearance. Dimpling is the process of bending and stretching (flanging) the inner edges of sheet metal components. In this case a hole will be drilled or punched and the inner edges of that hole will be flanged. This is said to add strength to the sheet metal, by essentially strength hardening the areas around the hole.

Material Joining

This project will contain two separate types of material joining. In the fabrication of the tray welding will be used to join the sides of the tray to the bottom of the tray. This will be done using tungsten inert gas metal welding. This type of welding was chosen because of its controllability and because of its availability in the S&G Metal Fab shop floor. The other type of joining will be done during the assembly and installation of the tray into the vehicle. For this reason it must be a reversible process and one that can be done using simple shop tools. This type of joining will be accomplished by some type of combination of nuts and bolt system.

Tungsten inert gas welding most commonly known as TIG welding is one of the strongest and cleanest types of manual welding available. The ability to control the amperage and flow of filler material makes this type of welding extremely flexible and desirable. For this reason and the availability of it on the S&G shop floor it will be used to weld together pieces of sheet metal to create the battery tray. A few of the tips from the article "10 Tips for Welding Sheet Metal" will be followed when creating operation sheets. The most notable tips are to use copper chills and argon gas to reduce heat in the welding area and weld using a back step process. The reduction of heat in the weld can help with the final strength of the finished product. By not getting the heat affected zone too hot. The use of the back step approach will help with lessening the chances of warpage, by breaking the weld into pieces as to not concentrate too much heat in one area at one time. This is a common practice when welding sheet metal and can also be accomplished by multiple spot welds done throughout the welded area. This approach again spreads the heat to different areas and lets other areas cool, to minimize warpage.

Design

Constraints

The design of the battery tray and process began with constraints determined by S&G Metal Fab. First the total price of the finished product based on direct material and labor was to be between $35 and $50. Indirect production costs were chose to be left out due to the relocation of the shop in the near future. Also the lack of employee benefits also negated indirect costs. For S&G to have a good understanding the costs were on based on the material and labor costs.

The $35 to $50 range was decided by current products out on the market. In order to be competitive S&G wanted to match or beat these prices with the production of the battery tray.

Next S&G decided that the battery tray must be manufactured in less than two hours. This was important, because the product is new, and shop space is limited, S&G wanted to be able to produce the part on an as ordered basis. This would allow the company to produce and ship an order in one business day, while not taking up valuable shop space with work in progress and large amounts of inventory. This constraint would be tackled by optimizing the manufacturing process and creating a set of operation procedures that clearly outlines the process and steps to create the battery tray.

Because S&G is a fairly small shop, the purchase of new equipment for the manufacture of the battery tray was to be avoided unless economic justification and reasonable purchasing prices could be obtained. For this reason tooling and equipment was limited to normal welding shop tools and machinery. This included welding machines, press brake, CNC plasma, grinding wheels, and various metal clamps.

Process

The first step in the project was to design the actual battery tray. Because design for manufacturing principles was used, the design of the part and the process were done on a very similar timeline. This is done to help in prevent unexpected manufacture hiccups once the first item is produced. The first part of the design was to ensure that its functionality was achieved. For a battery tray to be successful it must restrict all six degrees of freedom of the battery that it holds. These six degrees of freedom were restricted by essentially constructing a box around the battery. Next the box was altered to allow for battery terminal access and material was removed

for weight reduction purposes and aesthetics. This part of the design was done closely with S&G to ensure that the part met standards of the company before moving along with the design of the manufacturing process.

For the tray the sides were selected to be half of the total height of the battery to ensure that the battery would not rotate out of position when experiencing extreme angles. Also a metal strap was designed to allow ease of installation and removal of the battery. This strap also limited the battery from bouncing up and out of the tray. The tray will be manufactured using a solid blank cut out of aluminum sheet metal with gussets cut out of the sheet metal as well. The gussets will be used to support areas containing bends

The holes cut in the tray are present for two main purposes. First the holes reduce the total weight of the part by removing material. Being lightweight is a very desirable trait for off-roading applications and is desired by many enthusiasts. Although the part itself is very small and lightweight it is easier marketed to enthusiasts if extra effort is taken to reduce overall weight. The next function of the holes is to assist in the ease of cleaning the part. Often off-road cars experience extremely dirty conditions, such as mud, water, sand, dirt and clay. Because of this the ease of cleaning is also a highly desired trait. The holes in the part allow for the tray to be sprayed down with water and not fill up or collect. The water will drain out of the tray from the holes in the bottom and sides taking any dirt or grime with it. Two other functions of the dimpled holes are aesthetics and possibly strengthening of the rigidity of the sheet metal. In the off road industry dimpling body panels and sheet metal is an extremely increasing trend. Because of the fact that weight reduction is achieved from this process it is highly desired. By dimpling the battery tray it becomes aesthetically pleasing to enthusiast because of the common theme that can be carried throughout the process. Also the dimpling of the sheet metal could

possibly be used to increase the rigidity of the sheet metal. This is because of the stresses that are put in the metal around the hole. The strengthening of sheet metal through bead rolling has been around for years, but no significant research has been done on the dimpling process. Because the battery tray will not be under loads significant enough to shear the metal, the strengthening of the metal was not researched, however in the future it can be and could possibly be added to the literature to help increase future sales. The following figure is a computer model that simulates the design of the battery tray along with the battery enclosed in it.

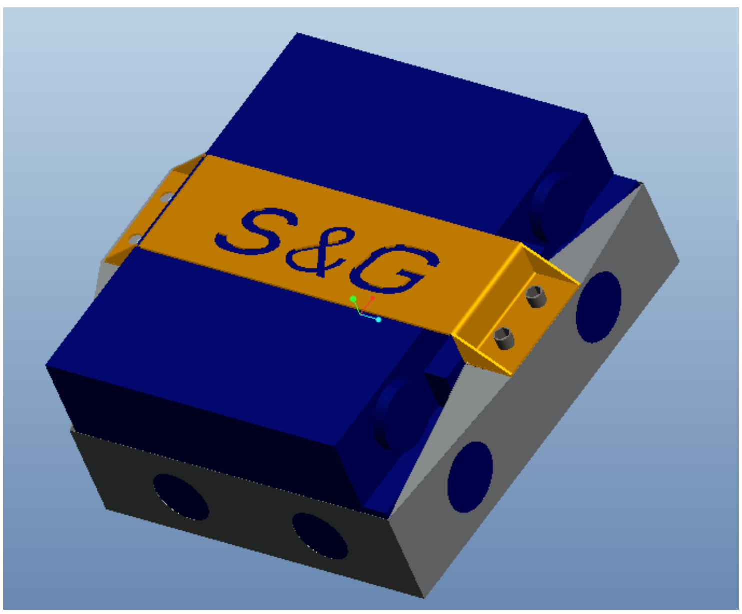

Figure 1: CAD model of Battery Tray

The next step in the process was to decide on the type of material that should be used for battery tray. This was a major decision in the project, as the material selection affected the overall cost of the part tremendously. Because of the different material properties each metal has

some are easier to work with than others, which in turn reduce production time and improve quality. To begin a list of possible materials was created. The list included plastic, wood, stainless steel, hot rolled steel, and aluminum. Next a list of customer desired traits was constructed. This list included rigidity, lightweight, corrosion resistant, cheap, easy to clean/maintain, and aesthetically pleasing. The customer requirements along with materials were then put into a matrix and each requirement was given a weight depending on the importance according to the customer. The weights averaged from 3 to 5. Next each material was ranked from 1 to 5 in each customer requirement category, with 5 being the best and 1 being the worst. The score was then multiplied by the weight of the category and then all scores were summed up for a final score. Table 1: Material Decision Matrix illustrates the material selection matrix explained above.

The resulting scores helped in the decision of material to be used. Although plastic had the highest score it was not chosen because of S&G's manufacturing capabilities. It was added to the matrix for future reference in case S&G decides to expand and begin processing plastics. Stainless steel and aluminum were tied in second place with 81 points. After evaluating both materials, 5052 h32 Aluminum sheet metal with a thickness of .090" was chosen. This was because it was a cheaper material and easier to weld. These two criteria helped in meeting the overall part price constraint.

Table 1: Material Selection Decision Matrix

	Material Selection Decision Matrix					
Customer Requirements	Weight	Plastic	Aluminum	Stainless Steel	Steel	Wood
Rigidity	5	5	15	25	20	10
Lightweight	4	20	12	8	8	16
Corrosion Resistant	4	20	12	12	8	4
Cheap < $45	5	50	10	5	15	20
Easy to Clean	3	6	12	15	9	3
Aesthetics	4	8	20	16	12	4
Score:		109	81	81	72	57

After choosing a material the next step was to design a manufacturing process to create consistent part amongst various operators. This included deciding on processes to use and documenting all the process to have a standardized procedure. The first step was to cut the sheet metal into the blanks that would be bent into the final shape. This was decided to be done on a Torchmate 2 CNC plasma cutting machine available at S&G Metal Fab. In order to cut the blank out a cad model was created and G-Code was generated using Torchmate software located at

S&G Metal Fab. In order to get a quality cut research was done on cutting settings for the CNC plasma cutter. In the end Torchmate's recommended settings were selected for the cutting process. Amperage was set to 40 amps, and voltage was set to 130 volts. Torch to work distance was programmed to be 0.06" and cut feed was set to 160 inches per minute. In order to leave clean edges a lead in of .125" was used and a piece delay was used in the program. After all settings were decided upon and the G-code was created the cutting step was completed.

The first step proved to be the most intensive step, as the finished part relied heavily on this initial step. The dimensions all had to be calculated using the bend deduction table mentioned earlier. This allowed for the heights to be the right dimension and the tabs to be located properly after the bending step had taken place. A value of 0.200" was deducted every time a bend occurred to allow for the growth of material around radiuses.

The next step in the process was to dimple all the holes in the blank. This process was done using a custom built dimple die that used a hydraulic bottle jack to press the dies shut. This step in the process seemed simple, however if not performed correctly it was found that the sheet metal would bow and distort. To prevent the sheet metal from distorting the dies needed to be completely bottomed out on each other. The sheet metal would initially bow, and then straighten out once the dies were fully compressed. Because of the highly manual and repetitiveness of this process it proved to be costly in labor and should be considered if volume of production were to increase.

The third step in the process was to bend the blank into the desired form. This step was one of the most complicated, because when initially designing the part it was thought of in its final shape, rather than starting out flat and being bent into shape. In order to simplify the

process a template with lettered bend lines was created to guide the operator on the bend order and where to make each bend. The machine was set to 2 tons of force.

The final step in the process was to weld in all the gussets and corner joints. This part of the process was developed closely with S&G as this was where their expertise existed. After consulting with operator and researching settings, a value of 20 volts and 145 amps was selected with the use of a thoriated Tungsten electrode sharpened to a point. Also 4043 rod with 100% Argon gas was used for this step. After all the steps were created documentation in the form of operation sheets was created to have consistent parts produced. Also a routing sheet was produced to show the order of operations for the production of the part. Detailed operation sheets and routing sheets can be found in the appendices of the report.

After all the process planning and design was completed a cost analysis was done. This was important for S&G to determine whether the product should be put into production and offered on their online website. First the direct material was calculated. To calculate the material costs the aluminum, hardware to connect the strap to the tray and the filler rod were all taken into consideration. These items were all summed up together and multiplied by a rework/scrap factor of 1.04 to give a total value of $7.03. Next the direct labor was calculated using the estimated cycle times and setup times. Again these were summed and multiplied by a rework factor of 1.02 to bring a total value of $26.78 which brings the total production costs per unit based on material and labor to $33.81 dollars.

Methodology and Results

In order to test the design of the battery tray and the process many prototypes were produced. The first prototype was created out of foam board. This was used to visualize the product and make sure that the battery did indeed fit into the tray. It was also helpful in testing the functionality of the product. By making a foam board prototype the access points of the battery terminals were able to be visualized and the ease of installing the battery was easily visualized. The next prototype was mad out of steel. This was done due to excess amounts of scrap available. This prototype allowed us to test the G-code created to assure that the program was indeed cutting the exact sequence that was designed on the CAD/CAM software. The last test that was done was a bend test and dimple test on scrap pieces of 5052 H32 aluminum sheet metal. By doing these tests it was confirmed that the processes were capable of being done without material or tool failure.

After the prototype was done mock setups of the processes were done to setup time. This was extremely important in calculating production costs. Then cycle times were estimated using operator experience and input and observing tooling and machinery in use. Some processes were timed for a single step and then multiplied to get an estimate. For example the dimple die process was the same for all twelve holes, so for the estimation the cycle time was recorded for three holes and then averaged, this was then multiplied by 12 holes to get the final estimated cycle time. This technique was also done with the welding and bending process. All estimates were done high to accommodate any unforeseen hiccups, also as an operator gets familiar with the product and process these cycle times should increase due to the operators learning curve.

Because a first article was has not yet been completed and production will not take place until the report is presented to S&G the actual metrics have not been determined. However material costs are accurate, and labor costs are very close and may even be on the high side. Based on the cost analysis done the part will meet S&G's requirements of a part costing less than $40 to produce. Also based on the estimated cycle times the process design meets the constraint of taking less than two hours to manufacture.

Because this was a new product there were no current metrics to compare against, however a new state does now exist. This new state does meet all design requirements set forth by S&G Metal Fab. This report can even be used as a stepping stone in the right direction for further research on launching the new product for online sales.

The following table illustrates the data used to create the cost analysis for production per unit. This information will be heavily used for the decision making process that S&G Metal Fab will use when deciding to move forward with production. This will also determine if the plan for production needs to be reworked to have a more optimal price range.

Table 2: Costs for Direct Material and Direct Labor

	Aluminum	Hardware	Filler Rod	Rework/Scrap	Total
Direct Material	$5.17	$1.00	$0.60	1.04	$7.03

	Operator Wage	Total Production Time	Rework		
Direct Labor	$15/Hr.	1.75 Hr.	1.02		$26.78
					$33.81

This table show how each value was calculated and the rates used for parts and labor. This will be important for S&G in case any engineering changes are made, the updates can be put into the table and a new cost of production can be calculated upon new changes in the planning process.

Conclusion

S&G Metal Fab asked to design a battery tray and manufacturing process and report a cost analysis. These are all functions of a manufacturing engineer would encounter during his or her career. This report demonstrates the knowledge learned at Cal Poly and application of it in a real world situation. Much was learned during this project that will be used in the future as I enter the engineering workforce.

A manufacturing process was designed and documented for S&G that met previously stated constraints. Most importantly the production time constraint of less than two hours was

met and the production costs was less than $40. All deliverables were met for S&G and a presentation is scheduled along with a session to manufacture the first part and inspect it to specified parameters. It will ultimately be up to S&G Metal Fab if the part is to be produced and marketed for online sales. Other than S&G Metal Fab's objectives the project also met the deliverables expected by the IME department at Cal Poly. A design was created, in the form of the manufacturing process and part design. This included the documentation of all steps in the process and computer design used to create drawings and G-code. An economic analysis of costs per unit based on direct material and labor was also done to allow for planning of possible part production.

This project was very satisfying in that there was much learning done on my own. Up until this project minimal sheet metal experience and CNC experience was obtained. This project forced me to learn about welding and plasma settings and how to create G-code for a sheet metal cutting process. Things like lead in and pierce diameter of plasma cut were new ideas and had to be researched extensively. I also learned that documentation in projects is extremely important. After having operators read operation sheets multiple times it was apparent that they must be highly specific in order for them to not be ambiguous, and for the end result to be achieved.

If I were to do the project over I would definitely be better on time management, this posed to be one of the biggest faults on my part. Because the entire project was self-scheduled for the most part the time spent on it was in long blocks instead of spreading the load out over the entire two quarters. Also I would have liked to do the first article tag before the final report was written so that comparisons could be made to estimated values and actual production values. One of the most useful aspects of this project was working with an actual company. This helped

in establishing real world constraints and limitations. Other projects at Cal Poly are a little more open due to the resources available, and this project turned out to be a little more challenging than most due to the limitation on resources and capabilities.

Overall this project accomplished many objectives. It satisfied objectives set out by both S&G and Cal Poly. Most importantly it helped me gain experience in managing and completing a twenty week project on my own. This was the most gratifying part of the project other than the use of CNC machinery. I would like to formally thank S&G Metal Fab for their help and participation in this project.

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Appendices

Routing Sheet

Part: **S&G Battery Tray**	Raw Material: **5052 h32 Aluminum sheet metal .090" thickness minimum 16" X 16"**
Rev: **1**	Planner: **Matthew Nartatez**
Total Unit Cost: $33.81	
Odyssey PC1200MJT Custom Battery Tray	

Op #	Operation	Machine	Set-up Time (hours)	Cycle Time (hours)	Accumulated Cost ($/unit)
010	CNC cut sheet metal	CNC Torchmate 2	.03	.16	10.03
020	Dimple holes	Dimple Die bottle jack	.02	.40	16.33
030	Bend Sheet	Ironworker press brake	.08	.50	25.03
040	Weld corner joints and gussets	Miller TIG welder	.16	.33	32.38
040	Kit/ package	N/A	N/A	.09	33.81

Operation sheets 010-040

Operation Sheet

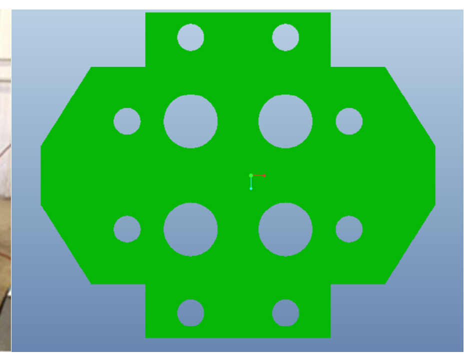
Part: Battery Tray
Operation #: 010 Operation Name: CNC Cut Sheet Metal

Machine: Torchmate 3

Tools: Quick Clamps

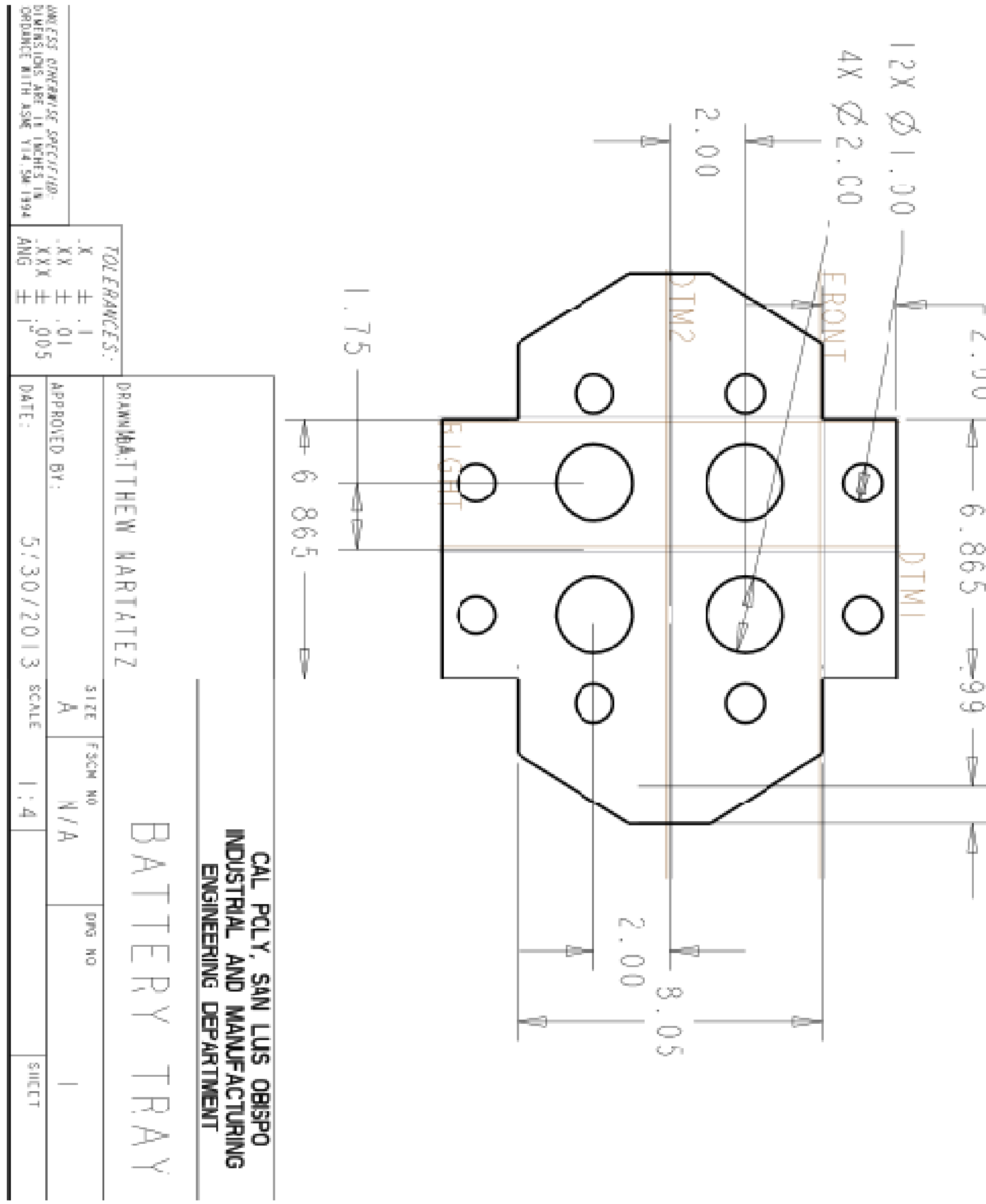
Methods and process conditions:

1. Clamp workpiece to back- left corner against table stops.
2. Select BAT_TRAY from programs
3. Run BAT_TRAY program.
4. Check cut out with template.



Set-up Notes: Voltage set to 145 volts
Amperage set to 40 amps
Use low profile clamps
*Note: Blank for strap is cut in this operation as well

Est. Set-up Time ______2.0 min______ Est. Cycle Time: ___10.0 min____________


CAL POLY, SAN LUIS OBISPO
INDUSTRIAL AND MANUFACTURING
ENGINEERING DEPARTMENT
BATTERY TRAY
DRAWN MATTHEW MARTATEZ
APPROVED BY:
DATE: 5/30/2013
SIZE A
FSCM NO N/A
DWG NO
SCALE 1:4
SHEET 1
TOLERANCES:
.X ± .1
.XX ± .01
.XXX ± .005
ANG ± 1°
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES IN
ORDANCE WITH ASME Y14.5M 1994
12X Ø1.00
4X Ø2.00
2.00
1.75
6.865
.99
8.05
FRONT
DTM1
DTM2
EIGHT

Operation Sheet

Part: Battery Tray
Operation #: 020 Operation Name: Dimple Die Holes

Machine: N/A

Tools: Dimple Die Press, 1” die, 2” die

Methods and process conditions:

1. Insert 2” dimple die.
2. Press the 4 center holes using 2” die.
3. Insert 1” dimple die
4. Press the 8 outer holes using 1” die.

*Notes: Dies must be completely bottomed out to keep the sheet metal flat. If die is not completely bottomed out sheet metal will bow and distort

Est. Set-up Time _____1.0 min______ Est. Cycle Time: ___25.0 min____________

Operation Sheet

Part: Battery Tray
Operation #: 030 Operation Name: Bend Sheet Metal

Machine: Ironworker Press brake

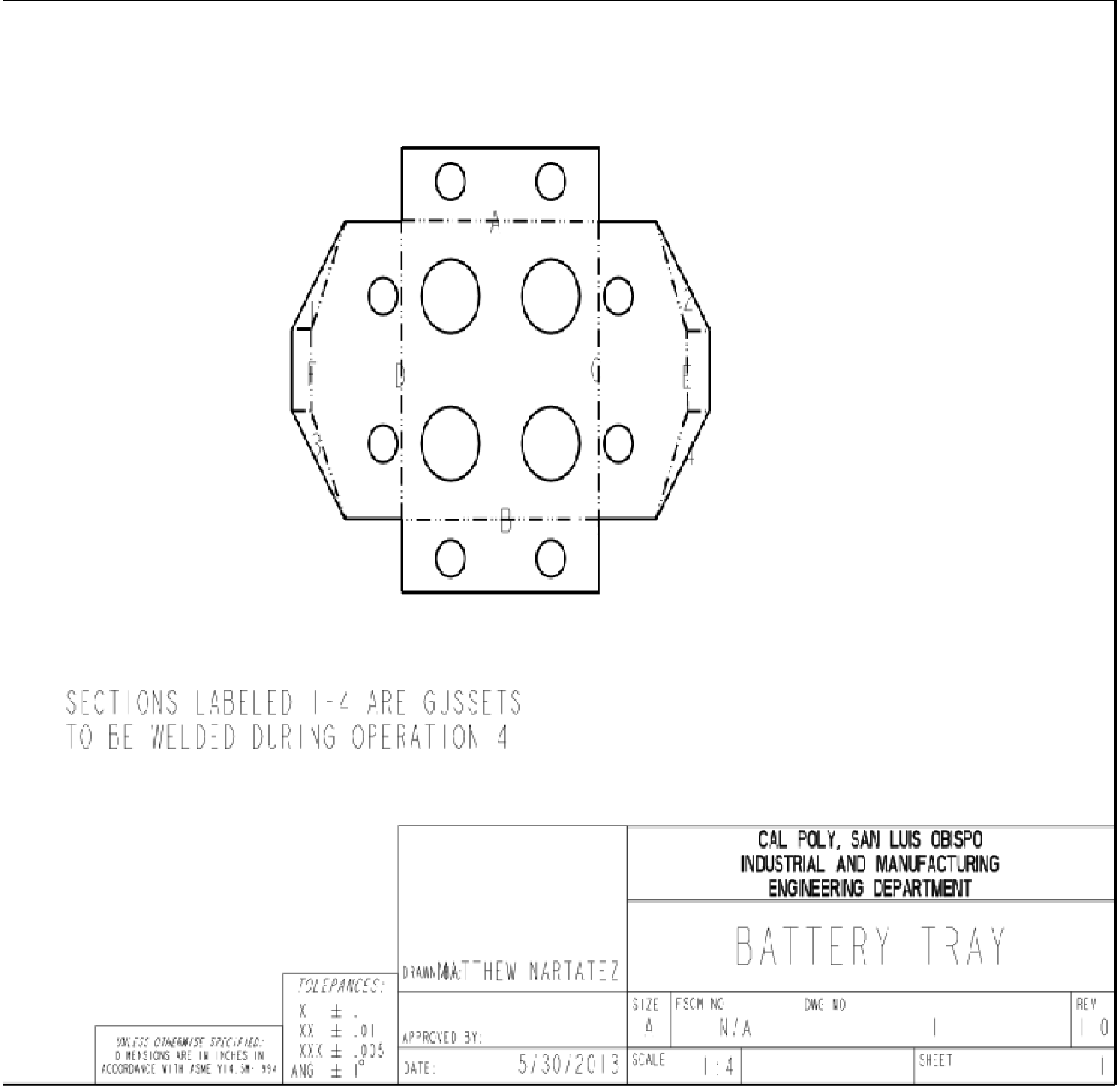
Tools: 90 degree bend block, 6" and 8" die attachments

Methods and process conditions:

- See attached sheet with bend lines
  1. Using the 6" die bend on lines A and B
  2. Using the 8" die bend along lines C and D
  3. Next using bend tabs on lines E and F

*Notes: Proper dies must be used to avoid distortion of the sheet.

Est. Set-up Time _____1.0 min______ Est. Cycle Time: ___25.0 min____________


A
B
C
D
E
F
1
2
3
4
SECTIONS LABELED 1-4 ARE GJSSETS
TO BE WELDED DLRING OPERATION 4
CAL POLY, SAN LUIS OBISPO
INDUSTRIAL AND MANUFACTURING
ENGINEERING DEPARTMENT
BATTERY TRAY
DRAWN MATTHEW MARTATEZ
APPROVED BY:
DATE: 5/30/2013
TOLERANCES:
X ± .
XX ± .01
XXX ± .005
ANG ± 1°
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES IN
ACCORDANCE WITH ASME Y14.5M-1994
SIZE A
FSCM NO N/A
DWG NO 1
REV 1 0
SCALE 1:4
SHEET 1

Operation Sheet

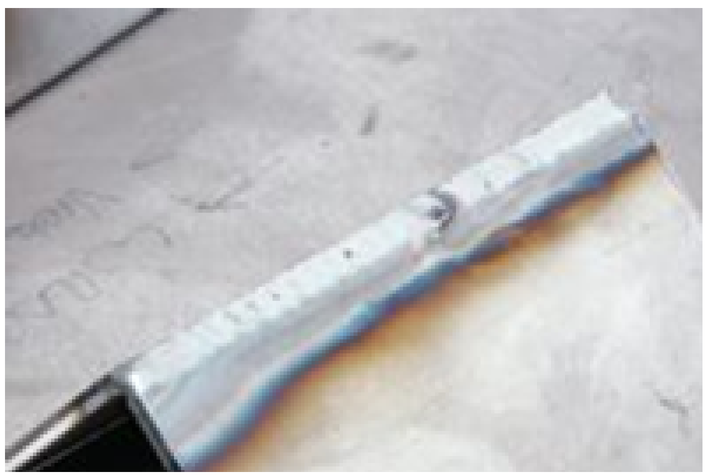
Part: Battery Tray
Operation #: 040 Operation Name: Weld Corner Joints and gussets

Machine: Miller TIG welder

Tools: 2% Thoriated Tungsten Rod, Various metal clamps,

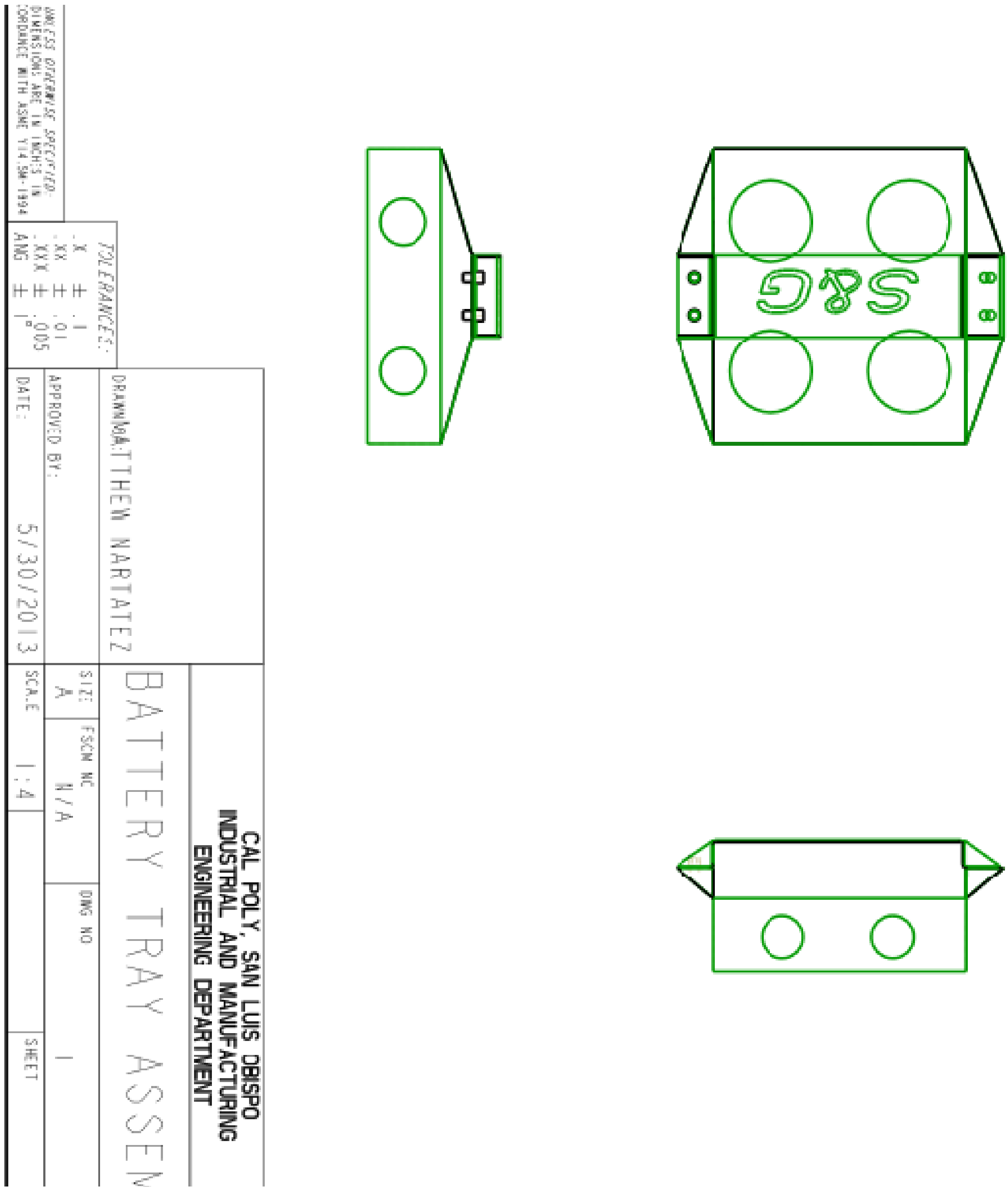
Methods and process conditions:

1. Using metal clamps line up outside corners and vertically weld corner joints
2. Add gussets to tabs and weld using clamps to hold in place.



*Notes: Tack welds should be used to keep ends from separating

Est. Set-up Time ____1.0 min_____ Est. Cycle Time: ___25.0 min___________


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES IN ACCORDANCE WITH ASME Y14.5M-1994
TOLERANCES:
.X ± .1
.XX ± .01
.XXX ± .005
ANG ± 1°
DRAWN BY: MATTHEW NARTATEZ
APPROVED BY:
DATE: 5/30/2013
CAL POLY, SAN LUIS OBISPO
INDUSTRIAL AND MANUFACTURING ENGINEERING DEPARTMENT
BATTERY TRAY ASSEM
SIZE: A
FSCM NO N/A
DWG NO 1
SCALE 1:4
SHEET
S&G

Operation Sheet

Part: Battery Tray Strap
Operation #: 010 Operation Name: CNC Cut Sheet Metal

Machine: Torchmate 3

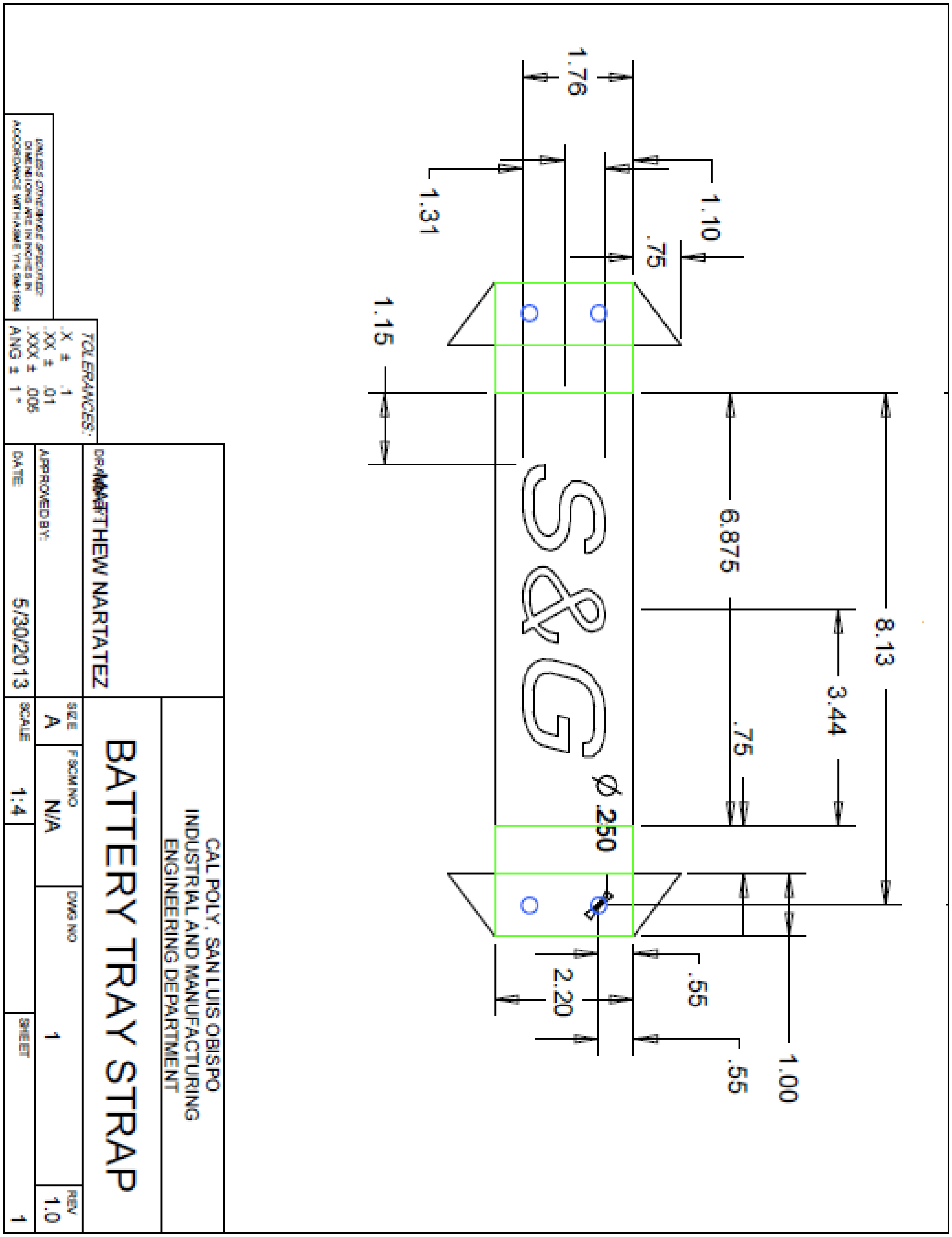
Tools: Quick Clamps

Methods and process conditions:

1. Clamp workpiece to back- left corner against table stops.
2. Select BAT_TRAY from programs
3. Run BAT_TRAY program.
4. Check cut out with template.

Set-up Notes: Voltage set to145
Amperage set to40
Use low profile clamps
*Notes: This piece will be cut along with the battery tray bottom.

Est. Set-up Time 2.0 min Est. Cycle Time: 10.0 min


1.76
1.31
1.10
.75
1.15
6.875
8.13
3.44
.75
Ø .250
2.20
.55
.55
1.00
S&G
TOLERANCES:
.X ± .1
.XX ± .01
.XXX ± .005
ANG ± 1°
DRAWN: MATTHEW NARTATEZ
APPROVED BY:
DATE: 5/30/2013
CAL POLY, SAN LUIS OBISPO
INDUSTRIAL AND MANUFACTURING
ENGINEERING DEPARTMENT
BATTERY TRAY STRAP
SIZE
A
FSCM NO
N/A
DWG NO
1
REV
1.0
SCALE
1:4
SHEET
1

Operation Sheet

Part: Battery Tray strap
Operation #: 020 Operation Name: Bend Sheet Metal

Machine: Ironworker Press brake

Tools: 90 degree bend block, 3” die attachments

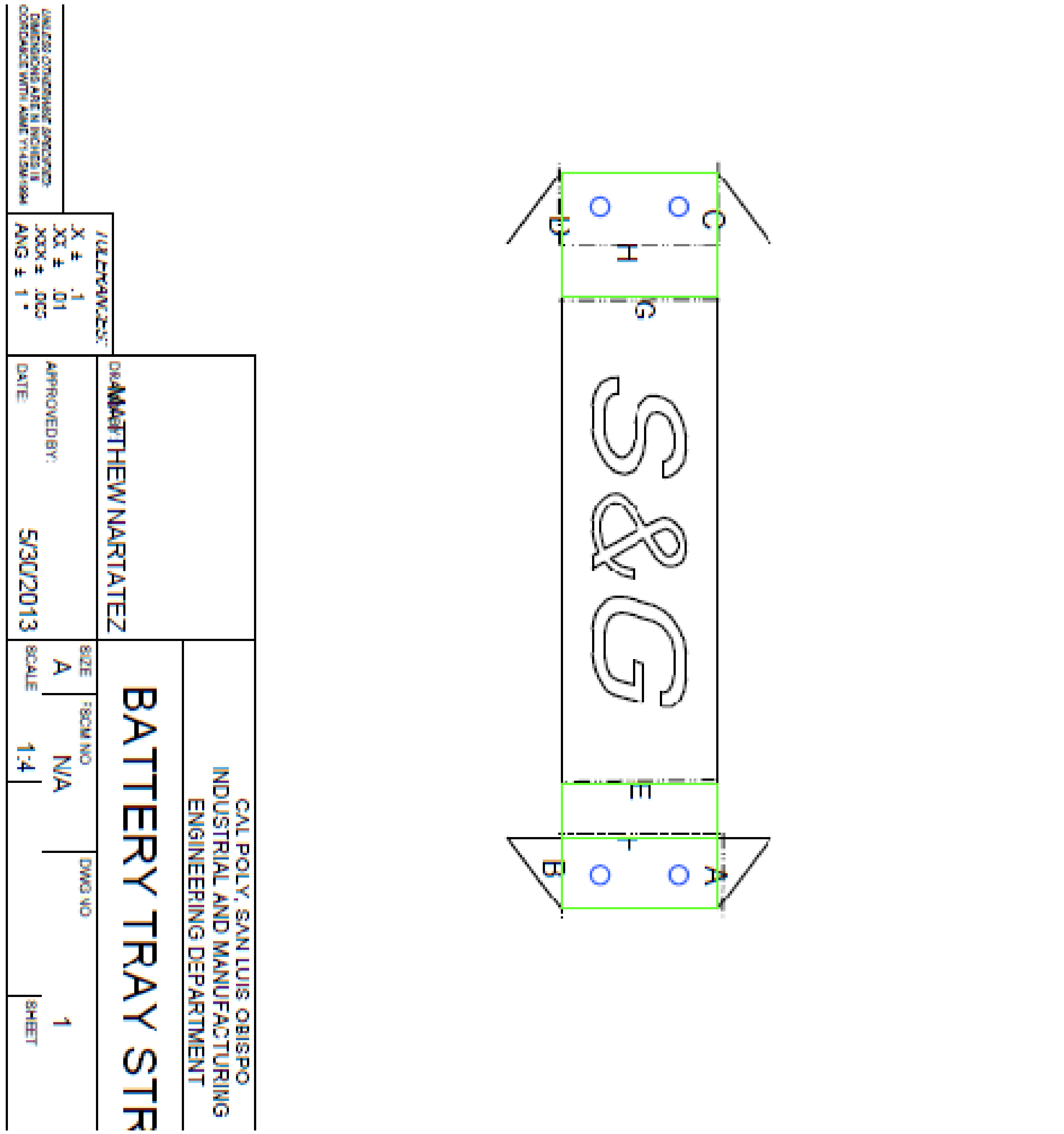
Methods and process conditions:

- See attached sheet with bend lines

1. Using template to line up bend lines, bend on lines in alphabetical order.
2. Use 2.0 tons of force
3. All bends are 90 degrees

*Notes: Proper dies must be used to avoid distortion of the sheet.

Est. Set-up Time _____1.0 min______ Est. Cycle Time: ___25.0 min____________


TOLERANCES:
.X ± .1
.XX ± .01
.XXX ± .005
ANG ± 1°
MATTHEW NARTATEZ
APPROVED BY:
DATE:
5/30/2013
SIZE
A
FSCM NO
N/A
DWG NO
SHEET
1
SCALE
1:4
BATTERY TRAY STR
CAL POLY, SAN LUIS OBISPO
INDUSTRIAL AND MANUFACTURING
ENGINEERING DEPARTMENT
S&G
A
B
C
D
E
F
G
H

Operation Sheet

Part: Battery Tray
Operation #: 030   Operation Name: Weld Corner Joints and gussets

Machine: Miller TIG welder

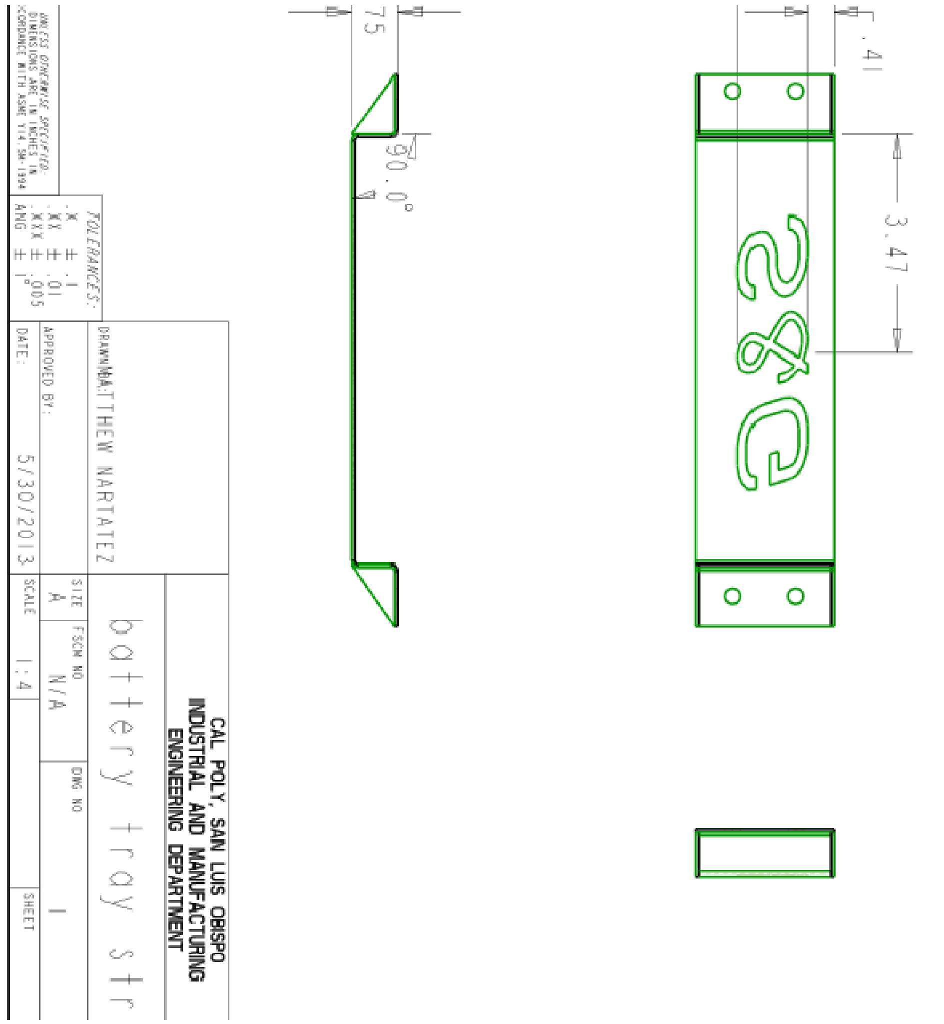
Tools: 2% Thoriated Tungsten Rod, Various metal clamps,

Methods and process conditions:

1. Using metal clamps line up outside corners and vertically weld corner joints.
2. Alternating sides should be done to prevent warpage.

*Notes: Tack welds should be used to keep ends from separating

Est. Set-up Time _____1.0 min______ Est. Cycle Time: ___25.0 min____________


.41
3.47
.75
90.0°
CAL POLY, SAN LUIS OBISPO
INDUSTRIAL AND MANUFACTURING
ENGINEERING DEPARTMENT
battery tray str
DRAWN BY: MATTHEW MARTATEZ
APPROVED BY:
DATE: 5/30/2013
SIZE A
FSCM NO N/A
DWG NO
SCALE 1:4
SHEET
TOLERANCES:
.X ± .1
.XX ± .01
.XXX ± .005
ANG ± 1°
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES IN ACCORDANCE WITH ASME Y14.5M-1994