Blast Containment Cell

A Baccalaureate thesis submitted to the
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College of Engineering and Applied Science
University of Cincinnati

In partial fulfillment of the
Requirements for the degree of

Bachelor of Science

In Mechanical Engineering Technology

By

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Thesis Advisor:

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# ACKNOWLEDGEMENTS

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ABSTRACT

L-3 Communications a Fuzing & Ordnance facility requires a select group of employees to handle explosives loading fuzes for use. The process is highly dangerous and adds a risk to human life. Training is required to handle explosive and a few personnel are selected to perform this task. These select few must load the explosive into a fuze and then securing it using some type of force.

The company in a effort to increase safety and reliability to the boosting process wants to create an automated cell for fastening fuzes after the explosives have been installed (Blast Containment Cell). This process is fully automated and no longer requires the operator to torque or roll form the fuze house cap. The old process required the operator to have hands and arms in harms way while securing the fuze

This project covers the integration of automation in a currently all manual process when installing and securing explosives in fuzes.

A blast containment building has already been built for the development of a safer environment for the operators. Three major hurdles will need to be overcome to remove the dangerous situation from the operator. The first obstacle will be the conveyance of the product into the cell. The second will be the creation of a torque machine. The current torque operation is done by hand. Third will be the integration of the automation to make everything work simultaneously.

The blast containment cell has many different assemblies that have to be constructed or installed to create the entire cell. The main parts have been defined in the design section of this report and are as listed, Torque machine, Roll form machine, 5 axis robot, window nest assembly, PLC control with HMI interface, and the blast cell doors.
INTRODUCTION & RESEARCH

Problem Statement

L-3 Communications a Fuzing & Ordnance facility requires a select group of employees to handle explosives loading fuzes for use. The process is highly dangerous and adds a risk to human life. Training is required to handle explosive and a few personnel are selected to perform this task. These select few must load the explosive into a fuze and then securing it using some type of force.

Interviews

The research into the blast containment cell was conducted with the personnel that use the current manual system. Teresa Vaughn (1) is the operator that installs the explosives in the fuzes. Conducting an interview with entailed finding issues there are with the current system. Teresa was able to explain the current process and how time consuming it is currently.

The operator must first wipe down the fuze with Isopropyl Alcohol to remove any dirt. Then an explosive pellet is installed into the fuze. An end cap in placed over the end of the fuze. The fuze is now placed into the machine that will roll the edge of the housing over to form a seal on the cap, see figure 1. The operator has a remote pendant that allows them to leave the build to operate the machine. Once outside the building they press the two palm buttons to operate the machine. The operator must then take the fuze out of the machine and check the seal for adherence.

The next interview poled the information of the current Manufacturing Engineer assigned to the program. Ed Hutchinson (2) has 25+ years in the manufacturing field He becomes a good resource for issues with the current system and areas that need improvement. Ed notes that the cycle time it takes to complete this manual process is very lengthy. Because of the manual operation of torque applied to the fuze, see figure 2. The torque operation is open for great improvements over the current method.

Figure 1: Current Roll Forming Machine
Figure 2: Current Torque Station
Patents

In researching current patents that my cover a similar theme it was determined that no current patent design for loading explosives into a fuze exist. Related patents show the use of a vessel to protect the operator from any explosive function of the machine or unit. The following individual Trott, B. D.; Backofen, Jr., Joseph E.; White, III, John J. (3) patented a design to house explosive for transit. This design would not allow the implementation of a machine to load explosives due to its size.

Working Products

Mistral Security System (4)
Mistral Security is the world leader in blast containment technologies for military, EOD and security agencies, airports, R&D and test laboratories, manufacturers of energetic materials and other critical infrastructure protection, K-9 training facilities, and explosives storage and transport. This technology ranges from semi-confined blast containment trash receptacles to fully confined blast containment vessels.

This technology also doesn’t allow the use of the current machinery required to perform the explosive loading function. The containers size and accessibility limits the amount of service work to be performed by large machinery, see Figure 3. See Appendix A for all research information.

![Figure 3: Explosive Trash Can](image)

Research and background information will be used to define what is needed in the design of the Blast Containment Cell. Taking this information the next step will be to construct a survey and collect data to see what the customer prefers in a new design.
SURVEY

Survey Features

The survey started with the evaluation of what possible design features would fit the project in hand. Design features were limited to 10-12 to find the customers' top desired features. The survey was given to operators, engineers, and senior management to establish the relevant customer features required for a successful design. The survey had a 1 to 5 scale with 1 being unfavorable and 5 being the most favorable, see appendix B for a sample of the survey and the final results. Information from this survey will help evaluate the current work flow. Aligning the high selected features will help set objectives to include in the design to make it successful.

Survey Results

Survey results are organized into averages and the highest averages dictate the features that are most important to the surveyor. Information from the survey will be plugged into the QFD matrix to establish the objectives for designing a robust system that meets the customer’s expectations. The features are evaluated for possible design characteristics and the following characteristics were chosen.

- Standard Components
- Material Weight
- Material Strength
- Cell Size
- Manufacturability
- Range of Motion
- Geometry Constraints
- Cycle Constraints

The quality section will evaluate the survey results and determine the relevant features to be used in the design of the final project. Focus will be on most favorable items and how to implement them into the customer satisfaction.
QUALITY

QFD Matrices

Entering the customer’s requirements taken from the survey into the “What” section of the QFD sets the groundwork for what engineering characteristics will be needed. Entering them into the “How” section provided the relationships to the design needs. Ratings are taken from the survey and have driven what is the most important Customer requirement.

The features listed in relation to their relevance to engineering characteristics create a relevant weight from the data compiled from the customer surveys. These percentages are used to find the objectives to focus on in the design process. The highest weighted items are Ease of operation, Range of Operation, Ease of manufacturing, and Reliability, see Table 1. Engineering Characteristics related to these in related weight are standard components, Cell size, and geometry constraints. See Appendix C for full QFD.

Table 1: Customer Importance

<table>
<thead>
<tr>
<th></th>
<th>Customer Importance</th>
<th>Current Satisfaction</th>
<th>Planned Satisfaction</th>
<th>Improvement ratio</th>
<th>Modified Importance</th>
<th>Relative weight</th>
<th>Relative weight %</th>
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</thead>
<tbody>
<tr>
<td>Ease of Operation</td>
<td>4.6</td>
<td>2.5</td>
<td>4</td>
<td>1.6</td>
<td>7.4</td>
<td>0.13</td>
<td>13%</td>
</tr>
<tr>
<td>Range of Operation</td>
<td>3.8</td>
<td>2.9</td>
<td>5</td>
<td>1.7</td>
<td>6.6</td>
<td>0.11</td>
<td>11%</td>
</tr>
<tr>
<td>Ease of Manufacturing</td>
<td>4.8</td>
<td>3.2</td>
<td>4</td>
<td>1.3</td>
<td>6.0</td>
<td>0.10</td>
<td>10%</td>
</tr>
<tr>
<td>Reliability</td>
<td>4.8</td>
<td>4.0</td>
<td>5</td>
<td>1.3</td>
<td>6.0</td>
<td>0.10</td>
<td>10%</td>
</tr>
<tr>
<td>Capacity</td>
<td>4.5</td>
<td>3.3</td>
<td>4</td>
<td>1.2</td>
<td>5.5</td>
<td>0.09</td>
<td>9%</td>
</tr>
<tr>
<td>Precision</td>
<td>4.0</td>
<td>3.8</td>
<td>5</td>
<td>1.3</td>
<td>5.3</td>
<td>0.09</td>
<td>9%</td>
</tr>
<tr>
<td>Flexibility of Gripping</td>
<td>3.5</td>
<td>3.2</td>
<td>4</td>
<td>1.3</td>
<td>4.4</td>
<td>0.07</td>
<td>7%</td>
</tr>
<tr>
<td>Maneuverability</td>
<td>4.0</td>
<td>3.9</td>
<td>4</td>
<td>1.0</td>
<td>4.1</td>
<td>0.07</td>
<td>7%</td>
</tr>
<tr>
<td>Two Person Operation (Safety)</td>
<td>4.4</td>
<td>4.5</td>
<td>4</td>
<td>0.9</td>
<td>3.9</td>
<td>0.07</td>
<td>7%</td>
</tr>
<tr>
<td>Ease of Programming</td>
<td>4.5</td>
<td>5.0</td>
<td>4</td>
<td>0.8</td>
<td>3.6</td>
<td>0.06</td>
<td>6%</td>
</tr>
<tr>
<td>Cost</td>
<td>3.2</td>
<td>4.0</td>
<td>4</td>
<td>1.0</td>
<td>3.2</td>
<td>0.05</td>
<td>5%</td>
</tr>
<tr>
<td>Accepts Multiple Tool</td>
<td>3.9</td>
<td>4.2</td>
<td>3</td>
<td>0.7</td>
<td>2.8</td>
<td>0.05</td>
<td>5%</td>
</tr>
</tbody>
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Table 2: Design Characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Relative Importance</th>
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<tr>
<td>Cell Size</td>
<td>17.8%</td>
</tr>
<tr>
<td>Geometry Constraints</td>
<td>17.5%</td>
</tr>
<tr>
<td>Material Weight</td>
<td>13.0%</td>
</tr>
<tr>
<td>Manufacturability</td>
<td>11.8%</td>
</tr>
<tr>
<td>Standard Components</td>
<td>11.1%</td>
</tr>
<tr>
<td>Cycle Constants</td>
<td>10.5%</td>
</tr>
<tr>
<td>Material Strength</td>
<td>9.0%</td>
</tr>
<tr>
<td>Range of Motion</td>
<td>5.5%</td>
</tr>
<tr>
<td>Material coating</td>
<td>3.9%</td>
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</table>
OBJECTIVES

Customer Features

The focus of the Ease of Operation in the design will require a single point of operation including a program that is turnkey and fully sufficient. The separate function for maintenance and setup will be a possibility to support easier use. The design needs to be as simple as possible to provide the best fit for multiple operators and minimal training.

Ease of Operation 13%
   a. Single control point
   b. Auto program function
   c. Maintenance / Setup Mode
   d. Single user interface

The Range of Operation will be determined by the current constraints of the building size. The building interior is 12” x 12”. Determining the distance of the machines from the service area and the travel of the conveyance device will be required.

Range of Operation 11%
   a. Cell Size
   b. Geometry Constants
   c. Range of Motion

The ease of manufacturing will consist of off the shelf tools and parts when availability allows. Construction design of support equipment will be considered for serviceability. Maintenance of the machines should have ease of access and ability to replace key components.

Ease of Manufacturing 10%
   a. Basic tools
   b. Standard parts
   c. Off the shelf replacement parts

In the Fuze industry the motto is the product can never fail. Reliability design of the complainants and the system is to be 100% every time with no failures. Lot size will have to be considered and the material properties will have to be consistent in all environments.

Reliability 10%
   a. Number of cycles (Lot Size)
   b. Controlled Environment (Temperature)
   c. Material Resist corrosion
Customer Features Continued

The cell configuration needs to provide the ability to repeat the same process with 100% repeatability. This means that tight tolerance will be held on the machinery and the conveyance system to provide repeatability.

Repeatability 9%
Proper design criteria specified in the following spec sheets:
  a. Consistent Torque
  b. Consistent Rolled Edge
  c. Robot cycles per spec sheet
  d. Conveyor transit

Safety 7%
  a. Door Guards
  b. Machine Guards
  c. Tool Fixtures interlocks
  d. System Lockout

Ease of Programming 6%
  a. Off the shelf PLC
  b. Off the shelf Programming Software
  c. Off the shelf panel view

Cost 5%
  a. Project must be less than or equal to $115,000 (per CER Capital Expenditure Request)
SCHEDULE

Design Schedule

The schedule defines the process flow of the design through fabrication and report out to the university. Note that final design and fabrication time will be utilized over the holiday break, see Table 3. The full schedule can be found in Appendix E.

Table 3: Schedule Dates

<table>
<thead>
<tr>
<th>Event</th>
<th>October</th>
<th>November</th>
<th>December</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
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<td>3D Modeling (CAD)</td>
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<tr>
<td>Design Finalized</td>
<td></td>
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<tr>
<td>Fabrication</td>
<td></td>
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<tr>
<td>Tech Expo</td>
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<tr>
<td>Final Presentation</td>
<td></td>
<td></td>
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BUDGET

Projected Cost

Design will have three phases to complete as projected. Machines will have to be upgraded to go from manual operation to automatic operation. The installation of some kind of conveyance device and the automation of the building will complete the system. Table 4 below shows the estimated cost to integrate these designs.

Table 4: Projected Cost per Design of each Component

<table>
<thead>
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<th>Items</th>
<th>Price $</th>
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<tbody>
<tr>
<td>Forming Machine (SDB)</td>
<td>$4,000.00</td>
</tr>
<tr>
<td>Torque Machine (GMLRS)</td>
<td>$24,500.00</td>
</tr>
<tr>
<td>Door Assembly</td>
<td>$14,000.00</td>
</tr>
<tr>
<td>Master Control</td>
<td>$3,500.00</td>
</tr>
<tr>
<td>Robot</td>
<td>$40,000.00</td>
</tr>
<tr>
<td>Interlock/Gate</td>
<td>$6,500.00</td>
</tr>
<tr>
<td>Surveillance/DCS</td>
<td>$6,000.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$98,500.00</strong></td>
</tr>
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</table>
ENGINEERING DESIGN PROCESS:

Blast Cell CONCEPT ideas

Brainstorming

The current Blast Containment Cell design is a manual operation. The interaction with the explosives is very dangerous. A blast containment room has already been built for the development of a safer environment for the operators. Three major hurdles will need to be overcome to remove the dangerous situation from the operator. The first obstacle will be the conveyance of the product into the cell. The second will be the creation of a torque machine. The current torque operation is done by hand. Third will be the integration of the automation to make everything work simultaneously.

In the section below are listed the brainstorming ideas in conceptual form. Each of the above obstacles was taken into consideration during these concept designs.

Blast Cell Concept Sketches:

Blast Cell Design Alternative Concept #1

This design would allow the blast containment cell to operate using two different windows for the operation. The product would be sent in on a conveyor and processed, then returning on the same conveyor. Pros and Cons for this process listed below.

PRO’s
- Never have to change setup
- Each window designated for one product
- Good Product separation

CON’s
- Can only run one unit at a time
- Capacity of the room fully utilized
- Length of cycle time waiting for unit
- Increase hardware to run to windows

Figure 4: Conveyors to Feed Machine
Blast Cell Design Alternative Concept # 2
This design would allow the blast containment cell to utilize on window and run two processes through the same window. The product would be set into a nest were a robot would pick up the unit and place it in the machine. The operator could then set another unit in the window while the first is processed. The robot would then place the finished unit into an outgoing nest and pick up the next unit to be processed. Pros and Cons for this process listed below.

PRO’s
• Utilize one window leaving room for expansion
• Only one conveyance device required
• Nest configuration allows faster process time
• Less hardware required to produce cell

CON’s
• Can only run one product at a time
• Require technical integration using robot

Figure 5: Robot to Feed Both Machines
Figure 6: CAD Design of Conveyor Concept
Figure 7: CAD Design of Robot Concept
Blast Cell Selection of Preferred Design

Blast Cell Evaluation

Evaluating both concepts using pros & cons to weight the differences and using the customer feedback from the survey a weighted evaluation was made on customer requirements. Criteria are listed in order of importance to the customer. Each criteria are also ranked from unsatisfactory to excellent. A rated score is given to show the best design concept for the operation. The blast cell weighted analysis in Table 5 shows the table that was used to determine the best design.

Table 5: Weighted Method of Blast Cell Design Evaluation

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Importance</th>
<th>Rating</th>
<th>Weighted Rating</th>
<th>Rating</th>
<th>Weighted Rating</th>
<th>Rating</th>
<th>Weighted Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease of Operation</td>
<td>20%</td>
<td>3</td>
<td>0.6</td>
<td>3</td>
<td>0.6</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>Range of Operation</td>
<td>20%</td>
<td>2</td>
<td>0.4</td>
<td>4</td>
<td>0.8</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>Ease of Manufacturing</td>
<td>15%</td>
<td>4</td>
<td>0.6</td>
<td>4</td>
<td>0.6</td>
<td>2</td>
<td>0.3</td>
</tr>
<tr>
<td>Reliability</td>
<td>15%</td>
<td>3</td>
<td>0.45</td>
<td>4</td>
<td>0.6</td>
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<td>Adequate</td>
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<td>Good</td>
<td>3</td>
</tr>
<tr>
<td>Excellent</td>
<td>4</td>
</tr>
</tbody>
</table>

Preferred Blast Cell Design Conclusion

The best concept for the process will be Concept 2 using a robot to convey parts. This will allow the most flexible process and free up space for future expansion.
Torque Machine CONCEPT ideas

Brainstorming

The torque machine will have to produce a finished torque of 60 Nm applied to the cap of the fuze assembly. Due to the construction of the fuze the unit must stay in the vertical position at all times during the torquing operation. Current fixture will have to be integrated to the process as required by the customer. Since the torque is more in the angular moment of operation a standard machine base can be used for support of the device. The torque operation can be of any exterior force such as electric, hydraulic or pneumatic.

Torque Machine Concept Sketches:

Torque Machine Alternative Design Concept #1

The first concept sketch design of the torque machine provides a stationary base, torque driver and a movable slide assembly. The torque driver will be mounted vertically at the table’s bottom. This will allow the driver to protrude through the table and install a drive socket. The slide assembly will then move down to secure the fuze in the socket. Once the fuze is secure the torque driver could apply the proper torque and release.

PRO’s

- Torque Driver mounted in a ridged position
- Socket for rotation mounted to driver
- Easy access to working area

CON’s

- NO easy way to align drive pins in socket
- Upper slide assembly alignment pin issues
- Alignment issues with robot installing part into the socket

Figure 8: Torque Machine Sketch #1
Torque Machine Alternative Design Concept #2

The second concept sketch design of the torque machine provides the same stationary base, torque driver and a movable slide assembly. The torque driver will be mounted vertically to the slide assembly. This will allow the driver to move up & down with the slide as needed. The table will have a mounted fixture to hold the fuze while torqueing. Once the fuze is secure the torque driver could apply the proper torque and release.

PRO’s
• Drive slide assembly used to provide downward force on part
• Fixture in a stationary position for robot alignment
• Socket can be set in with part pre-aligned
  Only one entry point for robot
Electric driver best utilized in this configuration

Figure 9: Torque Machine Sketch #2

CON’s
• Added weight to robot arm when sending in part and socket
• Hydraulic system would be hard to integrate

Existing Torque Driver Systems

Figure 10: Ingersoll Rand QM5 Series Driver

Figure 11: TorqLite Hydraulic Driver
Torqlite Hydraulic Torque Driver

This torque drive uses hydraulic pressure to produce the force need to fasten a part. This unit is used in hand tool application, but can be modified to mount permanent. Manufacture offers 8 different units with the ability to torque 100 to 60,000 foot pounds of torque. (8)

PRO’s
• Capacity to torque any current units
• Repeatability to Plus or minus 5 foot pounds
• Forward and backwards operations

CON’s
• Hydraulic Pump and Electronic controls required
• Have to fabricate mount to hold torque driver
• No onboard SPC or torque measurement captures
• Cost of unit in desired torque range is 15,000 dollars

Ingersoll Rand Torque Driver

This torque drive uses Electric to produce the force need to fasten a part. This unit is used in hand tool application, and can be mounted permanent. Manufacture offers 3 different units with the ability to torque 10 to 1000 foot pounds of torque. (5)

PRO’s
• Capacity to torque any current units
• Repeatability to Plus or minus 1 foot pounds
• Forward and backwards operations
• On board SPC for validation of unit
• Cost of Unit is 10,000 dollars
• Integrated controls provided with units
• PLC communications onboard
• ½” drive matches current fixture used in manual operation

CON’s
• No display outputs for screen controls
Torque Machine Selection of Preferred Design

Torque Machine Evaluation

Evaluating both concepts using pros & cons to weight the differences and using the customer feedback from the survey a weighted evaluation was made on customer requirements. Criteria are listed in order of importance to the customer. Each criteria are also ranked from unsatisfactory to excellent. A rated score is given to show the best design concept for the operation. The Torque Machine weighted analysis in Table 6 shows the table that was used to determine the best design.

Table 6: Weighted Method of Torque Machine Design Evaluation

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Importance Weight (%)</th>
<th>Torqite Hydraulic Torque Driver</th>
<th>Ingersal Rand Electric Torque Driver</th>
<th>Manual Torque Wrench</th>
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<tbody>
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<td>Weighted Rating</td>
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<td>Weighted Rating</td>
</tr>
<tr>
<td>Ease of Operation</td>
<td>20%</td>
<td>2</td>
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<tr>
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<td>20%</td>
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<td>3</td>
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</tr>
<tr>
<td>Ease of Manufacturing</td>
<td>15%</td>
<td>2</td>
<td>3</td>
<td>0.45</td>
</tr>
<tr>
<td>Reliability</td>
<td>15%</td>
<td>3</td>
<td>3</td>
<td>0.45</td>
</tr>
<tr>
<td>Capacity</td>
<td>10%</td>
<td>3</td>
<td>3</td>
<td>0.3</td>
</tr>
<tr>
<td>Precision</td>
<td>10%</td>
<td>3</td>
<td>4</td>
<td>0.4</td>
</tr>
<tr>
<td>Flexibility of Gripping</td>
<td>5%</td>
<td>2</td>
<td>3</td>
<td>0.15</td>
</tr>
<tr>
<td>Cost</td>
<td>5%</td>
<td>1</td>
<td>3</td>
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<td>2.30</td>
<td>3.10</td>
<td>2.85</td>
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</table>

Preferred Torque Machine Design Conclusion

Evaluation of the hydraulic and electric driver system using the criteria above in Table 6 it was determined that the electrical torque drive would be the best fit for the torque system. Easy of operation and range of operation plus reliability were the deciding factors. The hydraulic system was unable to meet the required constraints needed.
PLC CONCEPT ideas

Brainstorming

The PLC can be an off the shelf item. The important options on the unit will consist of number of I/O on board, the Ethernet capability, and the ability for expansion if needed. The system will need to be capable of 24VDC or 120VAC to meet any criteria required. On board visual LCD screen will be required for visual feedback. Also the ability to communicate with a HMI (panel view) device is required. Cost and software are also a concern to integrate and maintain the PLC program.

PLC Alternative Configurations

**Allen Bradley**
The MicroLogix™ 1400 Controllers features EtherNet/IP™, with on-line editing and a built-in LCD. This controller features a high I/O count, fast high-speed counter, and enhanced network capabilities with a backlight LCD. Stand alone PLC provides 32 digital I/O points. You can expand all versions with up to seven 1762 expansion I/O modules. (5)

![Figure 12: Allen Bradley MicroLogix PLC](image)

**PRO’s**

- Ethernet capability
- LCD screen on board
- Expandable up to 7 modules
- Well priced in market
- Ease of availability

**CON’s**

- Limited I/O on base unit
- On board memory limited
GE FANUC

The VersaMax’s powerful processors with up to 128K of memory for application programs, floating point math, real-time clock, subroutines, PID, Flash memory. It includes automatic I/O addressing - extensive diagnostics with an internal fault table and LEDs that indicate system faults and I/O forces. The CPUE05 processor has built-in Ethernet functionality. (6)

PRO’s
- Ethernet capability
- Expandable up to 8 modules
- Ease of availability

CON’s
- Complex User software for integration
- On board memory limited
- No on board LCD

Mitsubishi

The FX1N combines the benefits of an inexpensive compact controller with the flexible expansion capabilities of a modular control system. It can be expanded for up to 128 inputs and integrated PID controls. User friendly programming with MS windows based program. And hand held programming. (7)

PRO’s
- Easy programming
- Ease of availability

CON’s
- No Ethernet capability
- On board memory limited
- No expansion modules
- No on board LCD
PLC Selection of Preferred Design

PLC Design Evaluation

Evaluating both concepts using pros & cons to weight the differences and using the customer feedback from the survey a weighted evaluation was made on customer requirements. Criteria are listed in order of importance to the customer. Each criteria are also ranked from unsatisfactory to excellent. A rated score is given to show the best design concept for the operation. The blast cell weighted analysis in Table 7 shows the table that was used to determine the best design.

Table 7: Weighted Method of PLC Design Evaluation

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Allen Bradley Micrologics</th>
<th>GE Fanuc</th>
<th>Mitsubishi</th>
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<td>Language</td>
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<td>Weighted Rating</td>
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<tr>
<td>Ease of Operation</td>
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<tr>
<td>Ease of Manufacturing</td>
<td>15%</td>
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<td>0.45</td>
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<td>Reliability</td>
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<td>Capacity</td>
<td>10%</td>
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<tr>
<td>Precision</td>
<td>10%</td>
<td>3</td>
<td>0.3</td>
</tr>
<tr>
<td>Flexibility of Gripping</td>
<td>5%</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Cost</td>
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Rating

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<tr>
<td>Good</td>
<td>3</td>
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<tr>
<td>Excellent</td>
<td>4</td>
</tr>
</tbody>
</table>

Preferred PLC Best Design Evaluation Conclusion

Evaluation of the 3 PLC systems using the criteria above in Table 7 determined that the Allen Bradley Micrologics PLC was the best fit for the application. Easy of operation, Capacity, Cost, and Reliability were the deciding factors. The GE & Mitsubishi systems were unable to meet the required constraints needed for the system.
SELECTED DESIGN LAYOUT

Figure 15: Blast Cell CAD Rendering

Figure 16: Box Enclosures and interior cell layout
Figure 17: PLC Wiring Layout
SELECTED DESIGN ANALYSIS:

Blast Cell Components Selection

The following list of components will be used in the design of the blast containment cell. The selected design of the cell will consist of two main machines that will perform the actual functions. These two machines are a Roll Forming machine and a Torqueing machine. The Roll Forming machine is an existing machine that will be implemented into the automated cell. The Torque machine will be created and all design analysis will be shown below. Machines will be fed by a Fanuc 5 axis robot. This is an off the shelf purchase item to implement into the cell.

1. Roll form Machine
   a. Clamp Assembly
   b. Product Nest
2. Torque Machine
   a. Slide Assembly
   b. Product Nest
3. Fanuc Robot
   a. Gripper fingers
   b. Gripper Actuator
   c. Pedestal
4. PLC controls
   a. Main PLC
   b. Expansion Cards
   c. Light Curtain
   d. HMI Controls
5. PC Product control
   a. Web Cams
   b. Product Wicket
6. Blast Cell Doors
   a. Frame Construction
   b. Slide Assemblies
   c. Cylinders
   d. Proximity Switches

Figure 18: Selected Component Placement
Mechanisms & Stress Analysis

Torque Driver Mount Forces

The torque driver will be mounted on a standard machine base. Base will be constructed of steel and have a working surface of 3’ x 2’ and have a tubular leg structure. The torquing mechanism is an Ingersoll Rand electric driver. The center of the driver separate so the user can mount to their designed mechanism. Below is the force analysis of the frame assembly used to hold the driver to a off the shelf slide cylinder.

Figure 19: Free Body Diagram of Driver Mount Device

\[
\sum M_A = 0 \\
\sum Ma = Pxd - Pxd2 \\
\sum Ma = 5.3lb \times 8'' - 5.3lbs - 16'' \\
\sum Ma = 21.3lb/in
\]

\[
\sum F_x = 0 \\
A_x - R_B = 0 \\
A_x = R_b \times X \\
A_x = 2.65lb \times 8'' \\
A_x = 21.2lb \rightarrow
\]

\[
\sum F_y = 0 \\
A_y - W = 0 \\
A_y = W \\
A_y = 5.3lb
\]
Robot Forces

Mass of the cylinder being moved

\[ M = \left( \frac{\pi D^2}{4} L \right) \rho \]

\[ M = \left( \frac{\pi \times 2.87^2}{4} \times 7.6 \right) \times 0.0372 \text{ lb/in}^2 \]

\[ M = 1.82 \text{ lb} \]

Mass in relation to the X, Y, & Z axis

\[ J_x = J_y = M \left( \frac{L^2}{12} + \frac{D^2}{16} \right) \]

\[ J_z = M \left( \frac{D^2}{8} \right) \]

\[ J_x = J_y = 1.82 \left( \frac{7.6^2}{12} + \frac{2.87^2}{16} \right) \]

\[ J_z = 1.82 \left( \frac{2.87^2}{8} \right) \]

\[ J_x = J_y = 4.51 \text{ lb/in}^3 \]

\[ J_z = 1.874 \text{ lb/in}^3 \]

Inertia is measured at the point of gripping product. Inertia measured in the X, Y, & Z axis.

\[ a = 6'' \quad b = 2'' \quad c = 1.5' \]

\[ J_x = \frac{M}{12} \left( a^2 + c^2 \right) \]

\[ J_y = \frac{M}{12} \left( a^2 + b^2 \right) \]

\[ J_z = \frac{M}{12} \left( b^2 + c^2 \right) \]

\[ J_x = \frac{1.82}{12} \left( 6^2 + 1.5^2 \right) \]

\[ J_y = \frac{1.87}{12} \left( 6^2 + 2^2 \right) \]

\[ J_z = \frac{1.82}{12} \left( 2^2 + 1.5^2 \right) \]

\[ J_x = 12.285 \text{ ft} \cdot \text{lb/s}^2 \]

\[ J_y = 21.84 \text{ ft} \cdot \text{lb/s}^2 \]

\[ J_z = 1.365 \text{ ft} \cdot \text{lb/s}^2 \]
Determination of Material Properties

Multipurpose Aluminum (Alloy 6061)

A combination of good strength, corrosion resistance, and machinability makes this the most widely used aluminum (9). It has less strength than Alloys 2024 and 7075, but better corrosion resistance and weldability. It's heat treatable and resists cracking due to stress. Commonly used for vehicle parts and pipe fittings. Nonmagnetic. Temperature range is -320° to +300° F.

![Figure 20: Aluminum 6061 Material Properties](image-url)
Modeling

Geometric

The slide mount assembly consists of 6061 aluminum construction. It has an opening for the torque drive to mount to the supporting frame. Mount hole are drilled in the vertical part of the frame to fasten to the slide cylinder. Drawing for model is located in Appendix I.

Figure 21: Torque Drive Mount Support Assembly

Figure 22: Torque Driver Bench Assembly
The gripper finger assembly shown below will be used to grab the product and transport it to the machine. All products are cylindrical and the gripper’s dimensions conform to required tolerances. Gripper fingers are keyed to mount to an actuator and the hold area has a set of grooves for rubber inserts to assist in the holding of the product.

![Gripper Fingers for Retrieving Product (Used on Robot)](image)

Figure 23: Gripper Fingers for Retrieving Product (Used on Robot)

Door assembly is constructed of low carbon steel for rigidity and strength. The doors plate has to be made of Impact resistant A516 carbon steel. The door needs to be able to absorb some blast force if said explosion occurs. Linear slides will move the door side to side to access the 20” x 20” hole in the room’s wall. A main cylinder will drive the plate with commands from the PLC.

![Door Assembly Including Cylinder](image)

Figure 24: Door Assembly Including Cylinder
IMPLEMENTATION:

Fabrication of Components

The components used in the blast containment cell that needed creation were, Torque Drive table assembly, Gripper fingers, Fixtures to hold product, and Door Assembly. All of these components were created in the L-3 communications model shop. Drawings were provided with all material, tolerance, and assembly details.

Validation Process

Preproduction runs in the new blast containment cell currently total 78 operations. This process was defined with inert units of the actual fuze. All units torque to 50ft lbs with zero failures. Torque Driver controller captures all data process and can be downloaded to present SPC data. Below is a sample file of data collected.

If the fuze’s torque is above or below the limits it puts the system into error and notifies the operator of the torque limit error. The robot then places it in the window and will not run until the operator removes said fuze and resets system.

Figure 25: SPC validation of Torque Machine
ASSEMBLY

The blast containment cell has many different assemblies that have to be constructed or installed to create the entire cell. The main parts have been defined in the design section of this report and are as listed, Torque machine, Roll form machine, 5 axis robot, window nest assembly, PLC control with HMI interface, and the blast cell doors.

The blast cell doors have to be installed first and are used to secure any explosion that may occur during production. The doors are assembled in pieces which consist of outer frame with slide guides to allow the door to open and close. All frame and door construction is from ½” mild steel. The door will actuate using a 2”x 22” air cylinder. The door components are shown in Figure 26.

![Figure 26: Blast containment Cell door with air cylinder](image)

The 5 axis robot was picked for its versatility to perform angular functions required to move the product into each one of the machine for its function. The robot will serve both machine and be centrally located in the middle of the two machines. The robot will be mounted to a pedestal that allows it to perform at the same height as the machine using its 5 axis to their ability. The robot will also have a gripper actuator and the grippers designed to hold the product installed on axis 5. See Figure 27 & 28 for detail image.

![Figure 27: Robot Actuator with Grippers](image)  
![Figure 28: Robot mounted on pedestal](image)
The torque machine & roll form machine will install into the cell to either side of the robot. The roll form machine is an existing machine and only required electronic upgrades to communicate with the PLC described later in the report. The torque machine had to be designed and created from scratch. Detailed description in the design section of this report concluded the requirements and integration required. The table is a machine base measuring 24” x 36” and will hold all components required for the torquing operation. Torque machine has a slide assembly with internal cylinder used to move the torque drive up and down over the part. The table will hold a nest in which the part will be placed. Assembly of all created parts was performed before installation into the cell shown in figure 29.

![Figure 29: Roll form machine and torque machine installed in cell](image)

The next part of the cell is the nest assembly that is installed into the door opening to allow the operator to place a unit in the window to be picked up. There are two sets of fixtures that will be used to hold the unit. Each set has characteristics that align the unit before the robot picks up and places into the machine. There is a 1” plate of mild steel welded to the frame of the window to ensure positive placement of the fixtures every time they need to be changed out in figure 30. This placement also ensures that no further teaching of the robot position points are required.

![Figure 30: Nest assembly with laser sensors for part placement](image)
The last part of the blast Containment Cell is the integration of the PLC and the HMI that will coordinate and operate the whole cell. The components consist of one enclosure for the incoming power, one enclosure to hold the PLC and terminal strips for connections to all electrical components. The last enclosure will be used to hold the HMI touch screen that will be used by the operator to select product configuration. Light curtains are mounted on either side of the window opening to protect the operator while machinery is in operation. Figure 31 shows location of components.

![Figure 31: Controls for Blast Containment Cell](image)

All operator interfaces will be through the HMI touch screen interface shown in figure 32. This HMI will interact with the PLC to perform functions required in the cell. The operator will be able to select a product, enter lot size, start and stop running program, and view cycle time of the current part running in the process.

![Figure 32: Operator HMI interface](image)
DRAWINGS

Detail drawings provide complete specifications for the product including material selection, geometric dimensioning and tolerances. Refer to Appendix I for the product drawings.
WORKS CITED

APPENDIX A - RESEARCH

Interview with industry expert: Ed Hutchinson Manufacturing Engineer of L-3
Communication. 3975 McMann Road Cincinnati, OH 45245 08/28/2013
Mr. Hutinson has 25+ years in the engineering fields. He has been inolved in many blast
containment operations at L-3 over the past 15 years.
Possible area for innovation in the Fuze industry: automation of handling of explosive,
conveyance of materials to reduce operator handling, increase in cycle times.
He noted that all current designs are mechanical in function and time consuming for
operations
Mr. Hutchinson feels this will be a very importance process change for L-3 and will remove
the risk of harm to fellow employees.

Interview with industry expert: Teresa Vaughn production operator of L-3
Communication. 3975 McMann Road Cincinnati, OH 45245 08/28/2013
Teresa has 15 years experience applying explosive in Fuze system. She was able to provide
optimal input on criticality handling explosive.
She noted that there are powders and residue to deal with during the process. Risk to harm
in most cases is minimized by a plexiglass shield.
New personnel are sometimes scared to handle explosives
Teresa welcomes the new innovation to both help the operation of her current job and make it
safer at the same time.

Title: Design of Explosion Blast Containment Vessels for Explosive Ordnance Disposal Units
Descriptive Note: Final rept. 9 Sep 1971-30 Jun 1975
Corporate Author: BATTELLE COLUMBUS DIV OH
Personal Author(s): Trot, B. D.; Back fen, Jr., Joseph E.; White, III, John J.
PDF Ural: ADB016707
Report Date: JUN 1975
Pagination or Media Count: 117

Abstract: This report describes an experimental and analytical investigation of the design and
performance of spherical vessels for containment of explosive blast for application by
explosive-ordnance disposal teams. During this program a total of eight spherical steel
containment vessels were fabricated. The diameters and wall thicknesses investigated were
2.0 ft with 0.5-in. walls, 3.0 ft with 0.75-in. walls, and 4.5 ft with 1.0-in. walls. The vessel
ports were approximately one radius in diameter and completely closed by flat steel doors
overlaying the ports from the inside. During the course of this program a computer code was
developed which calculated the maximum elastic-plastic response and residual plastic strain
of spherical, thin-walled vessels in response to an internal, triangular shock wave followed by
a static internal pressure. The code in its present form uses measured shock-wave
parameters from Entoloted and static pressures which may be calculated for a number of
explosives.
Mistral Security System
Mistral Security is the world leader in blast containment technologies for military, EOD and security agencies, airports, R&D and test laboratories, manufacturers of energetic materials and other critical infrastructure protection, K-9 training facilities, and explosives storage and transport.

This technology ranges from semi-confined blast containment trash receptacles to fully confined blast containment vessels.


http://mistralsecurityinc.com/images/page_images/fullsize_1-image003.jpg

These systems are too small for explosive handling.

Container system is used mainly to contain public exposure.
APPENDIX B - SURVEY

EXPLOSIVE HANDLING MODIFICATION
CUSTOMER SURVEY

L-3 Communications a Fuzing & Ordnance facility requires a select group of employees to handle explosives during the loading of the fuze assembly. Information from this survey will help evaluate the current work flow. Creation of an automated cell will reduce the amount of human contact during dangerous operation of explosive loading in the future. Please fill out survey to help with a useful design.

How important is each feature to you for the design of a cell to handle explosives?
Please circle the appropriate answer.  1 = low importance  5 = high importance
(Avg.)

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<th>4</th>
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<td>3</td>
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How satisfied are you with the current means of handling explosives?
Please circle the appropriate answer.  1 = very Unsatisfied  5 = very satisfied
(Avg.)

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How much would you be willing to invest to improve the current process?

$5000-$10000  $10000-$20000  $20000-$50000  $50000-$100000

Thank you for your time.
### APPENDIX C – QUALITY QFD

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APPENDIX D - OBJECTIVES

Features listed on the survey were used to derive the product objectives. This list of features was considered, and the relevance to the produce design was determined. The following list of objects will be used to measure the design goals that will be set.

- Create a machine from the ground up to perform torque operation
- Modify existing Roll Forming machine to work with an automated cell
- Implement some kind of conveyance device to move part from cell window to machine.
- Automate cell to run fully automatic after operator place part into system.

Ease of Operation 13%
  a. Single control point
  b. Auto program function
  c. Maintenance / Setup Mode
  d. Single user interface

Range of Operation 11%
  a. Cell Size
  b. Geometry Constants
  c. Range of Motion

Ease of Manufacturing 10%
  a. Basic tools
  b. Standard parts
  c. Off the shelf replacement parts

Reliability 10%
  a. Number of cycles (Lot Size)
  b. Controlled Environment (Temperature)
  c. Material Resist corrosion

Repeatability 9%
  Proper design criteria specified in the following spec sheets:
    a. Consistent Torque
    b. Consistent Rolled Edge
    c. Robot cycles per spec sheet

Safety 7%
  a. Door Guards
  b. Machine Guards
  c. Tool Fixtures interlocks
  d. System Lockout

Ease of Programming 6%
  a. Off the shelf PLC
  b. Off the shelf Programming Software
  c. Off the shelf panel view

Cost 5%
  a. Project must be less than or equal to $115,000 (per CER Capital Expenditure Request)
## APPENDIX E - SCHEDULE

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## APPENDIX F - BUDGET

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<td>Torque Machine (GMLRS)</td>
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<tr>
<td>Master Control</td>
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</tr>
<tr>
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<tr>
<td>Surveillance/DCS</td>
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<td><strong>Total</strong></td>
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APPENDIX G – TORQUE DRIVER CONCEPT DESIGN

Torqlite Hydraulic Torque Driver

A time tested and proven tool design, square drive hydraulic torque wrenches offer a cost efficient option to handle a wide range of bolting make-up and breakout needs. The SU-XL Series torque wrench employs a "patented design" which increases accuracy and reduces the number of moving parts. Our robust and lightweight aluminum body completely encloses the drive train assembly keeping the crucial lubricant inside the tool while significantly reducing the opportunity for outside elements to contaminate the inside of the tool. Our standard SU-XL Series features eight different tools with capacities ranging from 100 to 60,000 foot pounds of torque using a 10,000 p.s.i. hydraulic pump.
Ingersoll Rand QM5 Series Fixtured Spindles

The QM Series Fixtured spindles were developed to meet the high production and duty cycles required in many of today's manufacturing facilities. Designed to work either alone or in multiple, these spindles when teamed with an IC Controller, will deliver the quality and performance your fastening application may require. The QM5 Series has a torque range up to 90 Nm and speeds up to 590 RPM. With their compact 44 mm center to center distance, optional spindle lengths and multiple mounting options, they will fit most any application.

<table>
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<tr>
<th>Model</th>
<th>CPN</th>
<th>Bolt Size</th>
<th>Torque Range Nm</th>
<th>Max Torque Nm</th>
<th>Free Speed rpm</th>
<th>Weight kg</th>
<th>Spindle Length mm</th>
<th>Flange mm</th>
<th>Square Drive in</th>
<th>Overall Length mm</th>
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<td>44</td>
</tr>
</tbody>
</table>

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APPENDIX H – PLC CONCEPT DESIGN

Allen Bradley
Bulletin 1766 MicroLogix™ 1400 Controllers build upon critical MicroLogix 1100 features: EtherNet/IP™, on-line editing and a built-in LCD. These controllers feature a higher I/O count, faster high-speed counter, pulse train output, enhanced network capabilities and backlight on the LCD. Controllers without embedded analog I/O points provide 32 digital I/O points, while analog versions offer 32 digital I/O points and 6 analog I/O points. You can expand all versions with up to seven 1762 expansion I/O modules.

GE FANUC
The VersaMax's powerful processors with up to 128K of memory for application programs, floating point math, real-time clock, subroutines, PID, Flash memory, and bumpless run mode provides a powerhouse of versatility in a small package. It includes automatic I/O addressing - extensive diagnostics with an internal fault table and LEDs that indicate system faults and I/O forces - freeing up the operator to concentrate on maintaining the highest quality. The CPUE05 processor has built-in Ethernet functionality.

Mitsubishi
The FX1N combines the benefits of an inexpensive compact controller with the flexible expansion capabilities of a modular control system. It can be expanded for up to 128 inputs and outputs and with a comprehensive range of special function modules. The FX1N also features a powerful integrated positioning controller.

The FX1N's communications and data link capabilities make it ideal for applications where the size of the controller hardware, communications features, special functions and processing speed are all critical.
FX1N series highlights:

- 14 to 128 inputs and outputs
- High processing speed (0.55µs per log. instruction)
- Ample program storage capacity (8,000 steps) and device ranges
- Integrated positioning controller
- Comprehensive range of special function and expansion modules for individual requirements
- Integrated PID controller
- Support for connection to open networks
- Integrated real-time clock
- User-friendly programming with MS Windows-based programming software package or hand-held programming unit
- Analog signal processing with optional expansion adapters
APPENDIX I – DRAWINGS FOR BCC COMPONENTS

<table>
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<th>Item Number</th>
<th>Document Number</th>
<th>Title</th>
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<td>2</td>
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**Section A-A**

**Notes:**

1. Applicable Standards/Specifications:
   - ANSI Y14.5M DIMENSIONING & TOLERANCING
   - ANSI Y14.4M ENGINEERING DRAWING PRACTICES
   - ASME Y14.10M ENGINEERING DRAWING PRACTICES
   - MIL-M-81659 MILITARY SPECIFICATION

2. Material made from 6061 Aluminum

3. Unless otherwise specified:
   - Surface Roughness
   - No Burns or Sharp Corners Permitted

**Inch**

**Dimensions:**

- Width: 2.755
- Height: 1.400
- Depth: 1.100
- Thickness: 0.020

**Dimensions for Clearance:**

- Width: 2.700
- Height: 1.380

**Drill for Press Fit:**

- Diameter: 0.170

**Drill for Clearance:**

- Diameter: 0.200