Stanley Black and Decker Slag Removal Design Project

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Stanley Black and Decker Slag Removal Process

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Final Capstone Report for 4600:471 Senior Design Project II Spring 2024

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Abstract:

A team of mechanical engineering students from the University of Akron have partnered with Stanley Black and Decker to improve their slag removal process. Their current process involves flipping large slabs of steel to grind the slag for the edges of the slab. Improving this process entails designing, building, and implementing a device to aid in this process. This device is to be safer, faster, and easier to use than the current operation. The team has defined several metrics of success to set goals for the project and to help determine the team’s success at the end. The design phase began with the team brainstorming ideas and sketching over 10 designs. To narrow these down, an objective tree and weighted decision matrix were used. The team also met with the sponsor to review the design sketches. From this, three feasible designs emerged, and preliminary CAD (Computer Aided Design) models were produced. From these basic models, 2/3 proved to be unsafe, or too complicated, and one design was concluded to be the best: the ‘book’. As the detailed design phase began, the team hit a major roadblock with motor selection. Because of this, a redesign had to be performed rapidly, and a new design, called the ‘rail’, emerged. Finite element analysis was performed on the frame to ensure its structural integrity. Next, detailed part drawings, assembly drawings, and a bill of materials were created. Over two weeks, the machine was built from raw materials and commercial parts. The machine was then tested against the defined metrics of success. The machine performed well against these metrics.
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Introduction

Problem statement

The mechanical engineering department tasks all seniors with a comprehensive design project. To fulfill this task, our group has partnered with Stanley Black and Decker to design and build a working contraption to aid in the removal of slag from large cuts of metal. Slag is solidified droplets of metal that form along a parts edge after being laser cut, see figure 1. Removal of slag is important to have a clean finished product. The current process of slag removal involves manually flipping these large steel plates and grinding the slag off. The complication is that these plates of steel can weigh up to 600lbs, far heavier than what an operator can do safely. This process of flipping the plate is where our team plans to focus our efforts.

Figure 1: Slag Formation on Ribs

The current operation is flawed. It is hazardous, labor intensive, and inefficient. An operator uses an industrial sized magnet chained to a crane to lift large slabs of metal onto a table. Then, a clamp attached to the crane is attached to the slab, and using the power of the crane, the plate is flipped. There is an incredible amount of trust in the reliability of the clamp. These slabs of metal, also called ribs, will eventually be used as back supports for large excavator buckets and couplers, see figure 3.
Metrics of Success

The team has outlined several metrics to determine the success of our project. These metrics are objective, so once the project is finished, an unbiased analysis of the team’s success can be conducted. Seen in figure 4, all seven of the metrics are listed. At the end of the report, the team will determine if we fell below, met, or exceeded expectations. These metrics entail the cost of production, the speed and number of steps of the new operation, the safety of Stanley Black and Decker, and the device's maintenance. For example, if the device makes the slag removal process take below four minutes, it can be concluded that the metric of success
was met. The metrics of success also help give direction to the designs. Cost, speed, ease of use, maintenance, and safety will be key areas to design around.

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Did not meet expectations</th>
<th>Somewhat meet expectations</th>
<th>Meet / surpassed expectation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keep the cost of the project less than the given budget, $5,000</td>
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<tr>
<td>Safety: OSHA certified, and less than 30lbs of operator force used in the process</td>
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<tr>
<td>Reduce the overall time to remove slag to be under 4 minutes.</td>
<td></td>
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<td></td>
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<tr>
<td>Operators and company are satisfied with the design. SBD implements new operation.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Ease of use: Reduce the number of steps required to remove slag, from 8 to less than 5.</td>
<td></td>
<td></td>
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<tr>
<td>Maintenance on the device can be completed in under 5 minutes once a day.</td>
<td></td>
<td></td>
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<tr>
<td>Design can perform for 2 years with proper maintenance.</td>
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</tr>
</tbody>
</table>

*Figure 4: Metrics of Success*

**Design Phase**

**Codes and Standards**

In the 1970s, congress created the Occupational Safety and Health Administration (OSHA). Since then, this administration has set many safety standards to improve workplace conditions throughout the United States. Because safety is one of the main design considerations for our team, understanding and abiding by OSHA standards are critical. For example, OSHA code 1926.753(d)(2)(i) states that “materials being hoisted shall be rigged to prevent unintentional displacement [3].” Good engineers strive to satisfy these workplace safety regulations, and this is what our team plans to do.

**Market Research**

This problem of flipping large plates is not unique to Stanley Black and Decker, so much so that there are commercially available machines that solve this problem. However, these commercially available machines were not a viable solution for a few reasons. To start, these machines are expensive, all exceeding the $5,000 budget by at least 5x. Also, all these machines had glaring safety issues, which is one of the main reasons to have such a machine. The final
reason is that Stanley Black and Decker’s operation required overhead clearance to get the slab of metal into position.

Machines like the ‘Steel Sheet Bundle Downender’ and the ‘Pre-slab upender’ help to inspire a few of our design sketches. The large amount of mechanical advantage integrated into the Downenders design was desirable, and the overhead clearance provided by the ‘Pre-slab Upender’ was desirable because SBD uses a gantry system to magnet up the large slabs. None of these commercial machines could satisfy everything that Stanley Black and Decker wanted.

Figure 5: Commercially Available Machines [1][2]

Sketches of Solution Concepts

Within the conceptual design phase of the project, many rudimentary designs were sketched to act as a drawing board for further research, and to begin the development of mechanical designs capable of meeting the needs of Stanley Black & Decker. These designs include various concepts that will later be narrowed down and modified into a final design.

First: This design utilizes a cage which would close around the part, allowing for the part to be safely lifted and rotated to the opposite side by rolling along a rail affixed to the table.
Figure 6: First Design

Book: This design utilizes a cage affixed to the table by a central axle, a book-like apparatus that allows the part to be flipped while enclosed in a cage to increase safety and speed. Both sides of the apparatus can be moved independently to allow either side of the part to be worked on.

Figure 7: Book Design

Pedestal: This design has a pedestal that rotates. The part gets magnetized to hold it in place, the operator can then scrape slag from the top and bottom.
Figure 8: Pedestal Design

**Gear:** This design utilizes the power input by a ceiling mounted hoist along with gearing, to raise both sides of the table vertically, allowing the part to be easily moved to the opposing side to access the bottom side of the part for work.

Figure 9: Gear Design

**Belt:** Straps or chains controlled by a suspended motorized axle rotate the part as the axle turns. The use of flexible materials would allow for the accommodation of many shapes of parts but increases the maintenance and initial cost of the solution.

Figure 10: Belt Design
Claw: This design uses two claws with rotating capabilities to grab, flip the part, and then place back down for the slag to be removed.

![Claw Design](image)

Figure 11: Claw Design

Mesh: This design consists of a table capable of being opened on either side, along with a centrally located axis of rotation, allowing for the part to be easily rotated and accessed from either side to remove slag.

![Mesh Design](image)

Figure 12: Mesh Design

Suitcase: This design consists of a simple box which the part could be placed in to be safely hoisted by a ceiling mounted hoist, removing the need for dangerous techniques previously utilized in this process.

![Suitcase Design](image)

Figure 13: Suitcase Design

Conveyer: This design utilizes a series of conveyor belts and pistons, creating an assembly line allowing two operators to continuously remove slag from multiple parts at the same time.
**Coin**: This design utilizes a ramped exit from a table allowing parts to be placed vertically on the ground before being rotated to the other side while being hoisted back onto the table.

**Airbag**: This design consists of two airbags which can be sequentially deflated and inflated to rotate a part. By partially deflating and inflating each bag the part could be smoothly rotated in a safe manner.

**V-Table**: This design consists of two plates hinged in the center, and pistons to lower the table into a “V” shape allowing for the component to be easily transferred to the other side before being raised for descaling.
Decision Tree & Weighted Decision Matrix

To rank the design sketches in an objective manner, an objective tree and a weighted decision matrix were used. The designs were ranked in the context of being able to achieve our metrics of success. The objective tree, seen in figure 18, assigns weights to our prioritized design factors. There are three main categories for design factors: cost, luxuries, and performance. Factors such as size and appearance fell in the luxuries category, and speed and ease of use fell in the performance category. For example, safety is a critical aspect of our designs, so it has been assigned a weight of 0.3375, meaning that safety attributes over a third of our designs rank.

The weights created by the objective tree are used in the weighted decision matrix. This matrix scores each design’s design factors on a 1-10 scale and totals their score. This process can be seen in Figure 19. Evident from the figure, the top four designs were A, B, F, and A-1.
April 26th, 2024

These designs scored high primarily due to their success in the performance category and safety category.

![Weighted Decision Matrix](image)

**Meeting with SBD & Narrowing Designs**

To cap off the concept design phase, our group met with our contacts at Stanley Black and Decker to present our design sketches and discuss the feasibility of them. After discussion, four designs sketches stood out. They expressed safety concerns with designs such as the ‘Pedestal,’ and they like the creativity of the ‘Mesh’ design. Additionally, the team was able to learn more about the slag removal process, and the in-house manufacturing capability of SBD. Because of SBD’s approval of these designs, the team began diving deeper into the design phase. Starting with creating 3D models using computer software.

**Preliminary CAD Models**

1) **Pedestal**: The main selling point to this solution process is the speed of operation. In competition with the other two selected designs, (the Mesh and the Book designs) this design eliminated the need to flip the plate. However, in return for the increase in operation speed, the safety of the process is worse as the operator would need to be operation underneath the plate. Additionally, the method for clamping the plate to the pedestal raises other issues, such as marking centers of mass on each plate and abnormal plates with small cross sections where the center of mass may be located. The final roadblock with this design solution is the implementation of the arm supporting the clamp, as it is shown in figure 20 as a L-shaped bar that could once again interfere with clamping the plate close to its center of mass. It was because of the lack of consistent methods for locating the plates' center of mass as well as safety concerns for the operators that discouraged the team from selecting this design.
2) **Mesh:** While the pedestal was designed for increasing the speed of the process, the mesh was designed with safety in mind. The initial (Mesh V0) design sketch for the mesh included a hand crank and would have the table be manually flipped by the operator; however, after meeting with SBD they proposed an automated method to keep the operators completely out of the way of the plate flipping process. This design went through 3 different iterations until we reached a point where optimization seemed to conflict with some of the design criteria. Below is a brief synopsis of each iteration of the Mesh design including their preliminary CAD models.

   a. **Mesh V1:** The first version of the mesh design swapped out the hand crank for a motor and belt to help rotate the plate. Other differences between this version and the original design concept include solid plate doors and the first interstation of locking mechanisms for the doors. There were a few concerns with this model, the first of which was keeping the plate fixed inside the
compartment when flipping. Because the range of plate thickness was from 1.00 to 4.00 inches, smaller plates would not contact the insides of both doors and could come loose when flipping. Another issue is the extended time for the process to be completed. Taking out each of the locks and flipping the part adds a lot of time to the process and could deter the operators from using this method. Finally, with this design there is no way to keep the table from rotating when we do not want it to. The initial design, Mesh V0, had collapsible legs to keep the table stable when not rotating a plate, but these were scrapped because of the extra time it would add to the process. With all these critiques in mind, work on the next iteration started.

Figure 22: Closed View of Mesh V1
b. **Mesh V2:** The next iteration of the Mesh design generated some solution for the problems that plagued the first iteration. To begin, the table now would no longer rotate when not wanted because of a locking mechanism added to the stands of the table. Additionally, the doors now open perpendicular to the axis of rotation. Unfortunately, this solution does not have a clever way to solve the other problems of keeping the plate fixed inside and the longer process time with the locking bars slotting over the doors. While the number of slotting bars decreased to 2, one for each side, it still added unnecessary time to the operation.
c. *Mesh V3:* The final iteration of the mesh design resembles more of a table than its predecessors. This is because of an issue with the overall stability of the table. When using the stand from the first two iterations, if a plate inside the compartment is not fixed properly it may fall to one end and cause the table to fall over. This iteration still uses the locking mechanism added to the stands of the table to keep the table from rotating when not in use. The new solution for varying plate thickness in this design allows the doors to move up and down within the frame of the table (Figure 27 shows the maximum and minimum thickness accommodations). Unfortunately, this version is not perfect, as now we need a method to secure the doors when rotating. This proved to be a challenge design to create the ideal solution for. Even with great ideas such as changing the axis of rotation to travel along the length of the table rather than the width, this solution generated too many roadblocks, and for that reason it did not see any further iterations past version 3.
3) **Book**: The Book design is like the Mesh, as they both utilize an axis of rotation about the center of the table frame. The difference between the two being that in the mesh design the table is flipped, while in the Book design an external apparatus is flipped. The concept was initially thought to be powered using an overhead crane at the designated workstation within SBD warehouse. Unfortunately, using this crane would increase the amount of time for the procedure, so alternative forms of automation must be considered. This design shares similar issues with the Mesh like accommodating for varying thicknesses and extended operation time when compared to the legacy methods.
Selection of Final Design

With our three preliminary CAD models, we discussed how the operation of these designs would work. The idea we had been going off was using the overhead crane to lift the design then slowly lower it back down. This idea works but has some safety concerns. This led to a discussion about automation, whether that be motorization or hydraulic. Our brief research showed that it was possible to be done within the price range for all the designs. We still need motor specifications and load cases to do full calculations.
All our designs had problems that needed to be investigated. For the “Book” design we need to find a way to effectively flip the pages while keeping the employees as safe as possible and find a way to switch from rotating both pages to just rotating one. For our second design the “Mesh” has issues limiting the amount steps and parts of this design, having a way to stop the plates from moving inside of the case and a way to hold the table steady, we fear that with these added steps the employee might choose to forgo the use of the design resulting in them still using the old unsafe method. Our third design “The Pedestal” has an issue with how to safely secure the plate without risk of it falling and that the operator would have to reach under the plate to scrape slag off the bottom. Some of these issues were attempted to be fixed during our iterations as shown above.

With all this information, we proceeded with selecting our final design. We decided the “Pedestal” had too many safety concerns to be continued further. We decided that the “Mesh” and “Book” were both good solutions to the problem, but we found that the “Mesh” had too many issues that needed to be addressed and that we did not have enough time to resolve all of them. With that we decided that our final design would be the “Book”.

**Book Design**

The team began to dive deeper into the details of the ‘book’ design. To start, many iterations of the machine’s geometry were run. The overall size of the machine was designed to comfortably hold an average sized steel rib, while also managing the largest size rib with slight overhangs on each side, see figure 30. The ribs would lay flat on the book pages and would be pushed as far toward the axis of revolution as possible to prevent unnecessary sliding during the flipping process. The team also designed a locking pin mechanism to lock the book pages shut during operation.

Figure 31 depicts a thickness varying mechanism. This mechanism would allow the gap between the two book pages to vary between one inch and four inches. Because the steel ribs come in many different thicknesses, having a fixed gap width would result in lots of void space. This void space would allow the ribs to shift around during the flipping process. This thickness varying mechanism was deemed too costly to effectively build, so the idea was scrapped, and replaced with inserting foam mats to fill void space.
Motor Selection

Once motor selection came along in the design stage, the team realized that book design had a major flaw. Due to its geometry, motorizing the process would require a motor to overcome an extremely large moment. A motor that could generate that large of a moment would be out of the team’s budget. When running torque calculation for the book design, the team was finding values upwards of 2000 ft-lbs. Torque was calculated using the following equation, where $F$ is force, $d$ is distance from the axis of rotation.
\[ \tau = F \times d \] (1)

The team explored various power solutions to supply the torque needed for this design, including geared electric motors, pneumatic actuators, and hydraulic driven actuators. An electric motor capable of creating this power even utilizing a gear reduction would have a large footprint and would be more than our total budget for the project. Pneumatic actuators could provide the needed torque in a small enough form factor; however, the price and availability of these actuators keeps us from utilizing them in our design. Hydraulic rotary actuators provide enough power, come in a small enough form factor, but once again availability of the actuator itself, and the components needed to operate such a device made this solution unviable. After rotary actuators were ruled out as a power supply, the team explored using linear actuators as hydraulic pistons and four bar linkages to create the needed power but failed to find a viable solution. Motorizing the process was a critical component of the design the team wanted to succeed with, so the team decided to rethink the design.

Redesign – ‘Rail’

With the realized flaws in the book design, the team set out to fix those problems. The team took inspiration from the rail of a garage door and used segments of prior designs to create our final design: the ‘rail.’ The new rail design combined several key aspects from the book and mesh design, while also adding a rail system. The team retained the encapsulated cage feature from the book design and changed the load to be rotated about its center of mass like the mesh design. The new rail design also added a rail guided chain system.
Figure 32: Rail Design

The ‘rail’ solved all the issues we found in the book design, it fully enclosed the biggest rib, reduced the moment force during rotation allowing us to purchase a much cheaper motor. Torque was reduced as the motor was connected to a chain that went around the full arc of the table. With all these changes we found a design that had the positives of all our other designs and limited their negatives.

This design was split into three sub-assemblies: the table, frame, and cage. Each of these were planned to be constructed separately then combined and are the major structural components of the machine. The table, or main base of the machine, is made of steel tubing. It will have two main bearings mounted on it. It will have several parts welded on including a motor plate, the rail that guides the chain, triangles to hold sprockets, and plates to mount the table to the floor. It is over-designed to hold over 2000 lbs., making it the last part that would fail.
The frame is the main rotating part. It will be connected to the table by being welded to shafts connected to the bearings on both sides. It is made from square tubing and has 8 hinges made from square tubing welded to it. It can rotate 180 degrees and is just shorter than the height of the table.

The cage encloses the rib allowing it to be rotated. There are two that get mounted to the hinges on the frame. They are made from steel tubing and have latches mounted to keep them closed while rotating. It will also have a steel mesh welded to it to fully enclose the ribs.
Finite Element Analysis

We began FEA (Finite Element Analysis) of our design under an industry standard 1.6 factor of safety, and it resulted in little stress and deformation. High stress areas such as the bearing, bearing shaft, and cage frame ends were analyzed particularly. The material of the square tubing, A500 steel, has a yield strength of 46 KSI. It is also important to notice failure in welding regions is common in industry, so a yield strength of 35 KSI was used to evaluate the strength of our welds. With these points in mind, we can evaluate our FEA to confirm that no yielding will occur during the maximum load case.

Our first run FEA simulates a 1000 lb. distributed load across the expanded sheet, where the ribs will be set. This run of FEA has a peak stress concentration near the bearing and bearing shaft. This is as expected, for this shaft is meant to transmit the weight of the plate onto the table. The size of the bearing and bearing shaft are another component that was investigated.
optimizing for cost, but we found that any smaller size bearing, or shaft led to complications with the current load cases we had presented. It is for that reason we continued to use the 1.5-inch diameter shaft and bearing. The peak stress value is only 25 KSI which is well under the selected materials and welding regions yield strength. In this model the table legs, cage, and frame are made from 2.0” x2.0” x 0.25” sections of square tubing. This was an overestimate in terms of strength, as seen by the FEA results, so in our next design iteration we were able to select smaller cross sections to help minimize the cost of materials.

Before we can be sure of the next iterations smaller sizes of square tubing, we wanted to test a corner loading on our current design to make sure it would not fail. This simulation is shown in the figure above, as a 1000 lb. force is applied directly to the corner of the cage. This is a loading that we would not typically see in daily operations and has a higher peak stress of 31 KSI, but still falls below the maximum yield strength of the material and welding regions. Knowing that this iteration passes with oversized square tubing we can now try different variations of sizes to maximize our saving when purchasing material.
Our final iteration of the design uses three different sizes of square tubing. For the table we found that keeping the 2.0” x 2.0” cross section was important for stability, but we were able to cut the wall thickness in half (from 0.25” to 0.125”) and retain the same level of structural integrity. In terms of the cage, it is the main component responsible for transmitting the weight of the plates into the bearing shaft and bearing, and because of this, we opted to keep it as 2.0” x 2.0” x 0.25” square tubing. We also kept the bearing and bearing shaft as 1.5-inch diameter for the same reasons. Lastly, the cage assembly saw the biggest change, as it went from 2.0” x 2.0” x 0.25” to 1.25” x 1.25” x 0.188.” The main purpose of this sub-assembly is to connect to the cage in a way that completely locks the plate within the perimeter of the cage for it to be flipped. The force applied is distributed across the four parallel sections and into the cage at the location of the hinges on the rear side and the location of the two latched at the front side. The figure above (Figure 38) shows the same 1000 lb. distributed load as before, but now with the changes to square tubing sizes. You can see from the figure above that the peak stress occurs near the connection between the frame and the cage at one of the hinges on the bottom left side of the assembly. This peak stress value is 25 KSI which, once again, is well below the maximum yield strength of the material and welding regions. After we finished reviewing our FEA result, we finalized our selected components and began construction of a bill of materials.

**Final Component Selection**

The next step in the design process was to finalize the specific components being used. Because mechanical advantage was integrated into the design, a smaller motor could be used. A helical drive right angle gear motor was selected to power this design. This motor provided
the needed torque, is easily reversible, has a small footprint, and was well within the budget for the project. Given the gearmotor’s 23:1 gear reduction, this motor draws less than 2 amps at 90 volts DC, allowing us to use consumer grade power supplies and control solutions.

![Helical Drive Motor](image)

Figure 39: Helical Drive Motor

To maximize safety, the controls for this design utilize redundant actuators, automatic shutoffs, and emergency shutoffs. The controls consist of a momentary 6 pole switch, which is used to reverse the polarity from the power supply to reverse the motor, allowing for drive of the table in both directions in a simple manner. In conjunction with the momentary selector switch, the control panel includes two momentary push button switches, forcing the operator to keep both hands on the control panel while the motor is active, see figure 40. The control panel layout requires the operator to hold the selector switch and the button on the opposite side from the direction the lever is being held. This configuration keeps the operator’s hands occupied during operation, removing the possibility of an operator placing their hand on any area of the table which may create a pinch point or otherwise place the operator in danger. Limit switches are placed at the end of travel on either side of the table to keep the motor and operator safe from over rotating the table. The final switch on the control panel is an emergency stop switch, which cuts all power from the table when pressed in any scenario the operator feels unsafe. DC power is provided to the control panel through a 110-volt AC to 90-volt DC converter and speed controller made for controlling motors, this allows the operator to lower the speed of the table to their preferred pace. The low draw of the motor allowed the use of 14 AWG stranded wire, which was easily handled and allowed for a small formfactor case to house controls.
Latches were selected that were load rated at 2,000lb. The latches also have a safety lever, to prevent any accidental openings. One of the most important parts about the latches is that when the doors are latched the assembly will be close to perfect balance. Without the latches in place the table would not be able to rest in correct orientation.

Square tubing was selected because it is cheap, readily available, and extraordinarily strong. Initially, all parts of the assembly used 2.00” x 2.00” x 0.25” square tubing. However, after the first run of FEAs (Finite Element Analysis), the team concluded that several areas of the frame were overdesigned. In these regions, tube size and thickness were reduced, to help reduce overall cost and weight. The following are the new sizes for the 3 sub-assemblies utilizing square tubing.

- Table - 2.00” x 2.00” x 0.12”
- Cage - 2.00” x 2.00” x 0.25”
- Frame - 1.25” x 1.25” x 0.188”
The bearings were mostly sized based on the shaft. In FEA, we selected what we considered an above satisfactory bearing for our first run, and the FEA result supported our decision. However, when trying to minimize the size of the bearing and shaft, it was found that any size smaller would lead to massive redesigns involving decreasing square tubing cross-sections and overall weight. This was seen as a lost cause, as decreasing these metrics would limit the size of the table, and the table size was determined by the size range of our industry sponsors top 80% of processed plates and ribs. In short, the binding dimensions for the table, cage and frame were design constants that limited our selection for bearings and bearing shafts. We settled on using a 1.5-inch diameter bearing and shaft for our final assembly.
Commercial Bushings and sprockets were purchased from McMaster-Carr. The team choose bushings because the operation is low speed, and because they are a much cheaper alternative to bearings. The bushing and sprockets were sized such that the bushings could be pressed into the sprockets with an arbor press.

The expanded sheet is not essential to the functionality of the build, but it does provide convince for the operator. Its main purpose is to help keep smaller plates and foam spacers from falling between sections of the cage. While it also helps in dispersing the load of the plates evenly across the interior of the cage.

The hinges for the door are made from scrap sections of 1.25” x 1.25” x 0.188” square tubing. They are cut to a height of 2.25” tall and welded to the driven end of the frame sub-assembly. In total, there are eight hinges with four on each side of the frame. The hinges connect the cage and frame using 5.0” long, 0.5” diameter bolts. These hinges are important in the transition of stress along the cage to the frame and, as mentioned in the FEA analysis section, there is an area of high stress concentration near the bottom left hinge.
Selection of Final Design

After narrowing down part selection and ironing out all the small details within our assembly, we end with our final iteration (V5). The final assembly uses the curved rail as a path to guild the frame using chains. It is designed for flipping plates weighing up to 600 lbs. A key concept to utilize this design efficiently and safely is to align the center of mass of each plate as close to the center of rotation as possible. This will limit stress on the motor as it flips the plate. Our solution for the varying thicknesses of plate is to fill the inside of the cage with rubber spacers which will help to fix the plates in place and additional soften any impact forces.
Build Phase

_drawings_  
The First step in kickstarting the build phase of this senior design project was to make detailed engineering drawings for the build. Every single part contained in the bill of materials would need its own drawing. For the purchased parts, many engineering drawings were taken from online sources. For example, McMaster-Carr provides detailed engineering drawings for their sprockets on their website. For the welded frame components, detailed drawings with information regarding raw material cuts, staging, and welding were provided in the drawing. Any part that was being laser cut using SBD’s infrastructure would require a DXF file. These DXF files are set to a 1 to 1 scale of the outer profile of the part and can include any through holes in their geometry (see figure 62). Examples of these burned parts are the rail and the triangular support blocks.

![Part Management Folder of F1255](image)

Figure 48: Part Management Folder of F1255

Once all drawings, models and DXFs were created, they were sent to SBD to input them into their engineering document management system. Then, SBD created a job, which allocated hours and people to the build of the machine. The final model consists of over 40 parts, each of which have a model, at least one drawing attached, and DXF for all burned parts. In total there are over 150 documents within SBD’s document management system for our senior design project. During this process each of our parts were assigned a part number in the SBD system, with the top level being F1255 and all its components following the diction of F1255-X. In our final bill of materials, we listed each part with the newly assigned SBD part number, a brief description of the part, and the quantity of that part needed for the final assembly (For more information regarding the final bill of materials see assigned section).

The following figures are the drawings for each of the of three main sub-assemblies for the Table, Frame, and Cage. These sub-assembly drawings are what the team provided to the operators to help instruct them in the assembly of our final model. Each of the three sub-
assembly drawings shown below are the instructions for the fit and welding process. Each
drawing consists of all the necessary weld callouts and the dimensions needed to locate each
weld. Let it be known that additional sheets were added for other processes like cutting and
forming, but to keep our report clear and concise, they have been excluded. Looking at the
drawing below, one can see that each material is listed in a bill of materials that is specific for
the sub assembly (this is not to be confused with the bill of materials for the final assembly).
These sub assembly bills of materials are used to call out and annotate specific cut lengths for
square tubing. The naming format for each component of the subassemblies bill of materials
can be seen below.

**Figure 49: Naming Convention**

**Figure 50: Weld Drawing for Table**

<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>PART NUMBER</th>
<th>ASSEMBLY/QTY.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.00 x 2.00 x 0.120 x 61.00</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>2.00 x 2.00 x 0.120 x 38.00</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>2.00 x 2.00 x 0.120 x 32.00</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>2.00 x 2.00 x 0.120 x 37.00</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>2.00 x 2.00 x 0.120 x 27.00</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>2.00 x 2.00 x 0.120 x 24.00</td>
<td>4</td>
</tr>
</tbody>
</table>
Figure 51: Weld Drawing for Frame

Figure 52: Weld Drawing for Cage
The following set of drawings are for the top-level assembly, which consist of all 45 parts listed out in the bill of materials. Within this list of 45 parts, you will see the three subassemblies mentioned above, each of them assigned a specific part number. The table is F1255-1, the cage is F1255-2, and the frame is F1255-3. These four drawing sheets provide the final set of instructions needed for assembly.

Figure 53: F1225 Drawing Sheet 1

Figure 54: F1255 Drawing Sheet 2
Purchasing

Stanley Black and Decker restricted our vendors to only being approved vendors and this caused our part selection to be limited. With this, every purchased part to be from either Grainger or McMaster-Carr besides our steel tubing. These industrial suppliers have many common parts readily available for affordable prices. Stanly Black and Decker also allowed the team to use in-house parts without impacting our budget.
All the parts arrived at Stanley Black and Decker within two weeks. We spent that time preparing ourselves and the company for the building process, which included giving them all our drawings and communicating with them for when both the operators and the team could build the machine. After all the orders came through, the total cost of parts was $3,096, well under our $5,000 budget.

Figure 58: Square Tubing Purchasing Quote
Welding and Burns

Figure 59: Welding & Fit of the Table

Figure 60: Table Welds – Close Up
The cutting, staging, and welding of the major frame components went well. The team effectively communicated our designs with the welding technicians at Stanley Black and Decker. Due to the lack of precision manufacturing tooling, many dimensions were far out of their tolerance range. For much of the assembly this was not a concern; however, the dimensions of the frame are extremely specific as they need to fit within the table, attach to the cage, and have enough clearance when rotating to not interfere with the curved rail and chain guild.

Knowing this we made sure to design with some “slack” in our final assembly to help us fine tune the placements of key components such as the frame. Throughout assembly we also found that some welds created interference with parts and prohibited use from reaching the desired fit so a hand full of welds had to be sanded down to allow for proper fit. Operators also helped by providing suggestions for cutting, staging, and welding. With their input, we had a handful of adaptations done mid-assembly to help create a better final fit.

The most important thing about burned parts is that the DXF is a 1 to 1 scale of the model you want burned. Thankfully, we had no issues with scaling of burned parts and all our parts came off the plasma cutter with the appropriate dimensions. Burned parts are laser cut from giant slabs of steel, up to 12 feet long. They are stocked in the warehouse in bulk.
After getting all our square tubing and burn parts cut, we started the assembly process by attaching the three main sub-assembly’s (The Frame, Cage, and Table) to one another. This simple shell of the assembly allowed us to check that each part was cut to the correct length and ensure no interference when rotating.

Top Level Assembly
After we had finished checking for any interferences, we disassembled the model back into its three subassemblies. This was to make the rest of the fitting and welding easier for the operators. From this point forward, all we had to do was follow the prints and wait for the operators to weld on the remaining parts such as the motor housing and the sprocket supports. Once all the welding was done, we could put the three sub-assemblies together for the final time and connect the chain to the frame sub assembly.
Revisions

During the welding process, a major error occurred where the wrong sized shaft was welded to the wrong end of the frame. In result, the entire book frame had to be shifted an inch towards the rail side, no longer leaving any room for the chain mounting plate. On the fly, the team revised this region of the build by making chain connector blocks that rest upon the top and bottom of the frame. With these new chain connector blocks, there was major interference with the sprocket support triangle, so the triangles were spaced up using scrap square tubing.

![Weld Sprocket Support Triangles As Shown](image)

**Figure 65: Drawing of Sprocket Support Triangle**

Testing and Reflection

Testing

On our first test of the plate flipper, we realized that a small misalignment of the sprockets attached to the motor housing created a force that would be pulling the drive sprocket off the motor shaft. This proved difficult to fix, as the motor was contacting the table sub-assembly and prohibiting it from shifting forward. If we were able to shift the motor forward it would alleviate the alignment issue. The only way to allow for the motor to shift forward is to trim a notch out of the table where it is contacting the motor and re-mount the motor. After trimming the table and re-mounting the motor, we had more shaft available to set the driven sprocket on which eliminated the force which was pulling the drive sprocket off the motor shaft.
After making the revision, the team had a much more successful day of testing. The table fully encapsulated a medium-sized rib and flipped it within the time designated within our metrics.
Future Revisions

There are several changes that could be made to immediately improve the function and reliability of the machine. To begin, having a more permanent and study location to mount the limit switches would improve their longevity and actuation reliability. The team also wants to implement a manual locking mechanism to prevent the rotation of the machine. This would help prevent accidental rotations during machine downtime or if the motor malfunctions. There are also some tolerance stack-up issues in the rail region that may cause some unintended premature wear on the chain, sprockets, and chain guide. This would require minor positional adjustments in many of the sprockets to better align the chain with the chain guide and rail.

Rating of Metrics of Success

Out of the seven metrics of success, the team has determined that five of them have met or surpassed the team’s expectations. The team fell $2,000 below the assigned budget for the project, so it was easy to conclude the success for this metric. Regarding the safety of the project, it was hard for the team to honestly conclude absolute success for this metric. The 30lbs of operator force was satisfied. However, there were some safety issues that the team did not have the time to resolve. Overall, there are a lot of pinch points and shape edges on the machine that are unsafe. They could be resolved if the correct guarding is put into place.

The duration of the slag removal process was reduced significantly. Once a rib is placed in the machine, it can be flipped within 30 seconds, with a flip time of about 10 seconds. The large table size also allows for ribs to be flipped several at a time, further saving time in the slag removal process. Because of these factors, the team concluded that we met expectations for this metric.

The team’s contacts at Stanley Black and Decker were satisfied with the design and performance of the plate flipping machine, thus satisfying this metric of success. The number of steps in the process decreased from eight to four, thus satisfying that given metric as well.

Daily machine maintenance has been reduced to simply just checking the condition of the chain, chain guide, and sprockets. Making sure the chain is properly lubricated, and the chain guide and sprockets are not sustaining too much wear. This process can be completed in seconds, so this metric was considered successful. For the final metric of success, it is hard to give an accurate evaluation of the team’s performance, so the team did not do so.
Figure 68: Completed Metrics of Success

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Did not meet expectations</th>
<th>Somewhat meet expectations</th>
<th>Meet / surpassed expectation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keep the cost of the project less than the given budget, $5,000</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Safety: OSHA certified, and less than 30lbs of operator force used in the process</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Reduce the overall time to remove slag to be under 4 minutes.</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Operators and company are satisfied with the design. SBD implements new operation.</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Ease of use: Reduce the number of steps required to remove slag, from 8 to less than 5.</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Maintenance on the device can be completed in under 5 minutes once a day.</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Design can perform for 2 years with proper maintenance.</td>
<td>−−</td>
<td>−−</td>
<td>−−</td>
</tr>
</tbody>
</table>

Conclusion

For this mechanical engineering design project, our team sought out to design and build a machine to flip large slabs of steel to aid in the slag removal process. The team underwent a long and thorough design process, going through many design iterations, to develop a successful design. Finite element analysis was performed to confirm the structural safety of the design, and torque calculations were performed to select the properly sized motor.

The build and assembly process required many engineering drawings, a complete bill of materials with vendors, welding sheets, burn files, and lots of planning. The build took many man hours. Raw material had to be cut and welded into the main structural components of the machine, and commercial parts were assembled onto the machine.

Once the build was finished, the machine was tested and evaluated against the team’s own metrics of success. Overall, the machine performed well against these metrics, and everyone involved was satisfied.
References
All photos used in this report were created by the authors of this Capstone Report


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