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Senior Design Capstone: Using an Engineering Design Process to Create a Sawzall Wobble Fixture for Milwaukee Tools

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SENIOR DESIGN CAPSTONE: USING AN ENGINEERING DESIGN PROCESS TO CREATE A SAWZALL WOBBLE FIXTURE FOR MILWAUKEE TOOLS

by
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DEDICATION

To my mother and father, I owe you the world. It is so very fitting that you are both successful educators, as I feel I owe much of what I have learned about dedication, persistence, and compassion to you. You have shown nothing but support to me from the very beginning with anything I have pursued, and for that I can never thank you enough. Both of you gave me the confidence to travel so far from home to follow my dreams, and without your continued support I would not be the person I am today. I love you both.

To my coaches and teammates, you made Mississippi feel like a home away from home in both the best and worst of times. Thank you for becoming a second family to me.

To my roommates, no one could have guessed that four young men from all over the country could become brothers in a state none of us had been to before. Your friendships, memories, and conversations will be cherished forever, and I truly hope to remain close in the future.

ACKOWLEDGEMENTS

To Dr. Tejas Pandya, thank you for your continued support toward our group during this capstone project. In nearly every lecture you deliver during your courses, the meaningful life lessons and truly heartfelt advice given to guide your students' futures does not go unnoticed, and I want you to know that it is greatly appreciated.

To Mr. Reed Rushing, Ms. Shelby Baird, and all the folks at Milwaukee Tools, thank you for your sponsorship for the design project and your kindness and hospitality during the visit to your facilities. The project group and I hope that the product we designed can serve you well at your facility.

To my group partners, Ben Savino and Alejandro Sarabia, thank you for your partnership and teamwork during this process.

ABSTRACT

TYLER JESSE MOORE: USING ENGINEERING DESIGN PROCESS TO CREATE A SAWZALL WOBBLE FIXTURE FOR MILWAUKEE TOOLS
(Under the direction of Dr. Tejas Pandya)

The overall objective of this design project was to successfully design a fixture to expedite the repairs of Sawzalls at the Milwaukee Tools repairs facility in Greenwood, Mississippi. This project was executed in accordance with guidelines set forth by the Senior Capstone Design class at the University of Mississippi as well as the quality engineers sponsoring the project at Milwaukee Tools. The fixture was created utilizing an engineering design process with the goal of allowing technicians to press two Sawzall wobbles onto an angled Sawzall wobble shaft using an arbor press with just one press. By beginning with a straightforward problem statement, a clamping fixture was able to be concepted and prototyped to complete this goal. The final fixture design was presented before faculty and industry members at the conclusion of the semester.

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1. INTRODUCTION

Per requirements for graduation, Mechanical Engineering majors at the University of Mississippi are directed to take the capstone design course ME 438 during the spring of their senior year. Students are assigned to design teams of three with the goal of utilizing skills they have acquired in mathematics, sciences, and engineering to create an innovative design solution to an engineering problem within the community. Teams are required to reach out to organizations or industries within the Oxford area to identify such engineering problems, allowing them to work with these sponsors toward a solution to their problem. Teams are expected to design, analyze, and produce a working model of their solution to be presented to faculty members and various industry specialists at the end of the semester. This process is used to mimic real-life engineering issues, enforcing lessons in solving applicable engineering solutions while working within a team. Additionally, students' improvements in communication and leadership skills will stick with them for the rest of their careers.

1.1 CAPTSONE OVERVIEW

Students are graded and assessed on a number of specific checkpoints throughout the capstone process. Firstly, the team was to identify a specific industry or community-based design project by a certain deadline with approval of both the design sponsor as well as the course instructor. Next, a questionnaire was to be formulated to prepare for the creation of product design specifications. The questions within the questionnaire were intended to be asked to capstone sponsors during meetings with the sponsors or tours of their facilities in order to identify a voice of customer. The voice of customer allows engineers to determine exactly what is desired within the product they will be designing for their sponsors. Once product design specifications were noted and recorded, various concepts to solve the problems presented by the sponsors were to be created by design groups using a specific engineering process. These designs could be created using drawings, sketches, or CAD software. Amongst the designs created by groups, groups were directed to select one concept using a concept selection matrix. After one concept was selected, a Design Failure Mode Effects Analysis document, or DFMEA, was to be created and updated throughout the remainder of the capstone process. Another document, a design logbook, listing individual team members and their ideas and task lists, was to be recorded throughout the design process, seen in Appendix [E]. A design checklist, helping guide the design process was also created, viewable in Appendix [F]. The capstone process culminates in a capstone exhibit and presentation where students are instructed to prepare a tri-fold poster to display the aspects of their designs along with any working model, prototypes, or animations that were created. Dress for students at this exhibition is business formal, and they are expected to receive and answer any questions from faculty or industry members viewing capstone projects. Finally, a finalized design report was to be turned in at the end of the semester containing all documents described above as well as telling the overarching story of the capstone process. A list of important dates for the design process is viewable in Table 1.

Table 1: Important Dates

Milestone	**Date**
Project Identification	2/10/2021
Facility Tour	2/17/2021
Questionnaire/PDS Turn In	2/12/2021
Team Meeting	3/9/2021
Project Exhibition Presentation	4/20/2021
Final Project Report	4/30/2021

1.2 DESIGN PROCESS OVERVIEW

The design process utilized in this capstone was provided by machine shop technician Matt Lowe and contained six main steps to be executed in a specific order of operations. [1] The first step of the design process involved creating a problem statement. A problem statement tells a story, describing in very general terms what exactly needs to be accomplished by a design. Additionally, the problem statement is to elaborate on any constraints placed on the design. The problem statement is the cornerstone of the engineering design process and should be reviewed and looked back on continuously. It is also recommended that a site visit is conducted before creating the problem statement so engineers can hear first-hand information of the problem that needs to be solved from the source. Once the problem statement is written, writing the outline for the project immediately follows. The outline budgets out time for the remainder of the project, placing deadlines and time goals for the group moving forward. After the problem statement and outline are solidified, engineers can begin creating specific drawings, sketches, and CAD models to solve the problem described in the problem statement. One concept is to be selected by the group once it is decided that it provides a suitable solution to the problem statement. A bill of materials, and therefore a project budget, are then to be constructed in order to describe how the selected concept can be brought to fruition both physically and monetarily. The design process concludes with a conclusion report which is presented to the project originator. This report details achievements that were met during the design process along with any conclusions and recommendations.

1.3 PROJECT SELECTION

For the case of this design project, a sponsorship from Milwaukee Tool was acquired. Communications were established between our design group and two quality engineers who work at the Milwaukee Tool repair facility in Greenwood, Mississippi via the course instructor Dr. Pandya, as it is common for Milwaukee Tool to sponsor groups for the University of Mississippi senior capstone project. Milwaukee Tool is a manufacturing company that manufactures, markets, and repairs power tools for commercial and recreational use. The quality engineers at Milwaukee Tool provided our design group with a specific problem for us to design a solution to.

2. PROJECT OVERVIEW

The Milwaukee Tool repair facility in Greenwood, Mississippi is responsible for the repairs of all Milwaukee Tool branded handheld tools sent back for repairs within America. One of the tools repaired at this facility is called a Sawzall. A Sawzall is a handheld power saw which essentially acts as a portable jigsaw with a reciprocating blade used to cut a variety of materials such as wood and piping. A Milwaukee Tool Sawzall can be seen in Figure 1. [2]

Figure 1: Milwaukee Tool Sawzall

Within the Sawzall are mechanical parts that often require repairs when sent to the repair facility. These mechanical parts include a “primary wobble,” a “secondary wobble,” and an oddly angled “wobble shaft.” The wobbles are essentially circular bearings with elongated shafts protruding from them, somewhat resembling a lollipop. Below, the wobble shaft can be viewed in Figure 2, the primary wobble in Figure 3, and the secondary wobble in Figure 4.

Figure 2: Primary Wobble

Figure 3: Secondary Wobble

Figure 4: Wobble Shaft

When these pieces are combined, they serve the purpose of turning the rotational motion of the motor within the saw into the translational motion of the sawblade. In order to repair these pieces, the primary and secondary wobbles need to be pressed onto the wobble shaft using an arbor press. Since the wobble shaft is not perfectly straight and is instead at a peculiar angle, the current method of pressing these wobbles onto the shaft involves technicians having to hold the shaft by hand and use the arbor press a few different times to press around the entire wobble. A technician using this current method to press the wobbles onto the angled wobble shaft can be seen in Figure 5.

Figure 5: Current Method of Sawzall Wobble Repair

The quality engineers at Milwaukee Tool tasked our design group with designing a fixture capable of holding the wobbles and the shaft so that the top piece is level, allowing the arbor press to push the wobbles onto the shaft in a single press. Deliverables expected included a fixture that could be utilized in the manner as described above, a set of clear instructions on how to use the fixture, plus drawing and assembly instructions for how to make more fixtures.

2.1 QUESTIONNAIRE

In order to create a higher understanding of what exactly was desired by the Milwaukee Tool quality engineers in a designed fixture as well as what parameters were required to be met, a questionnaire was created to help obtain more information. The questionnaire was created with the intent of asking the written questions while on a tour of the Milwaukee Tool repair facility. Questions were broken into different categories, such as questions about dimensions of the parts themselves or questions directed at the technicians who will be using the designed fixture. The questionnaire used by our design team can be seen in its entirety in Appendix [A].

2.2 TOUR OF FACILITY

Armed with a questionnaire hoping to gain a more detailed understanding of the task at hand and help to identify the voice of customer, our design group traveled to Greenwood, Mississippi on February 4, 2021 to tour the Milwaukee Tool repair facility. While on the tour, we got to witness the overall repair process of all tools moving through the facility. Tools requiring repair are delivered in trucks on one end of the warehouse where they are then invoiced and sorted into bins identifying what type of tools are in each. From there, the tools are sent to their respective repair stations in the middle of the warehouse where the damage to the tool is assessed and documented. If the tool is salvageable, technicians request what specific parts are required to repair their tool, then required parts are delivered to their station. If deemed unsalvageable or not worth the cost of repair, a notification is sent to the tool's owner that a replacement will be sent their way and the broken tool is scrapped for usable parts. Finally, once the tools are repaired, they are sent to the far end of the warehouse to be packaged and shipped out to their respective owners. Essentially, tools flow from one side of the warehouse to the other during their repair process. According to the quality engineers, the whole process is completed in a manner of only a few days. While seeing the repair process as a whole was important to grasp the scope of our design project, the most important part of the tour was seeing the Sawzall technicians at work pressing the primary and secondary wobbles onto the wobble shaft using an arbor press. The arbor press apparatus used in the Milwaukee Tool facility is shown in Figure 6, with a detailed view of the arbor press baseplate seen in Figure 7. A technician was also kind enough to allow us to film her pressing the primary and secondary wobbles onto the wobble shaft. Images of the wobbles on the shaft before being pressed onto the shaft as well as after being pressed onto the shaft are viewable in Figures 8 and 9, respectively.

Figure 6: Arbor Press

Figure 7: Arbor Press Base Plate

Figures 8 and 9: Pre-Press and Post-Press

The dimensions of the arbor press and baseplate were documented as well as the dimensions of the primary wobble, the secondary wobble, and the wobble shaft. Additionally, we were able to ask all questions from the questionnaire to the quality engineers and the technicians. Upon leaving the facility, the quality engineers provided us with a primary wobble, a secondary wobble, and a wobble shaft to aid and assist in our design of a suitable fixture.

2.3 VOICE OF CUSTOMER

Thanks to our prepared questionnaire and facility visit, our group was able to obtain a better grasp on the voice of customer for this product. The voice of the customer essentially summarizes the customer's expectations and preferences. In the case of our design project, the customer for our product is the workers at the Milwaukee Tool repair facility itself. Specifically, those workers in charge of repairs of the Sawzall wobble bearings and the quality engineers overseeing the process. This product was to be used by them on a daily basis in order to ease the process of applying the wobbles onto the wobble shaft. By making the process easier, an immense amount of time would be saved in the repairs process; allowing Milwaukee Tool to repair more tools per day, saving them money. With a better understanding of the voice of customer, our design group was finally ready to create our capstone's problem statement.

2.4 PROBLEM STATEMENT

By summarizing and streamlining all information obtained thus far in the design process, a problem statement was drafted:

> "Milwaukee Tool, a manufacturer of hand tools, manufactures a power saw called a Sawzall. When sent in for repairs, two "wobble" bearings must be pressed onto a shaft using an arbor press. This shaft forms a 150^{o} angle rather than being perfectly vertical. Due to the angled nature of the shaft, multiple presses of the arbor press are required to mount each wobble onto the shaft. This current process of pressing the wobbles onto the shaft is time consuming, inconsistent, and risks damaging the parts being repaired by placing direct pressure onto them. To reduce repair time, our group was tasked with designing a fixture

that allows both wobbles to be pressed onto the shaft with a single use of the arbor press."

This problem statement was to be referenced for clarity during the remainder of the design process.

3. PRODUCT DESIGN SPECIFICATION (PDS)

The Product Design Specification, or PDS, is a comprehensive document used to lay out in as much detail as possible the requirements that must be met to design a successful product. If possible, most of the items documented in a PDS should be quantitative or have units of measurement. This provides physical constraints to the abstract ideas of the problem statement. A PDS is created toward the beginning of the design process and updated regularly, guiding engineers toward viable concepts. [3] The full PDS for this design project can be viewed in Appendix B. Some highlighted requirements worth noting from our PDS include that the fixture must withstand over 1100 presses per year (based off the number of Sawzall's repaired in the 2020 calendar year) and the fixture must withstand over 8 tons of pressure from the arbor press. Additionally, dimensions of parts necessary for the design of concepts are located in this section.

3.1 SAWZALL WOBBLES

Since Milwaukee Tool was unable to share with us CAD files of the primary wobble, secondary wobble, and wobble shaft, our design team took our own measurements of the received parts using calibers and reproduced models as accurately as possible in the CAD software Creo Parametric. [4] A 3D rendering of the primary wobble is shown in Figure 10. From this created part, 2D drawings were created of the primary wobble showing dimensions such as height, diameter, hole diameter, and thickness. These drawings can be seen in Figures 11 and 12. All dimensions shown are in centimeters.

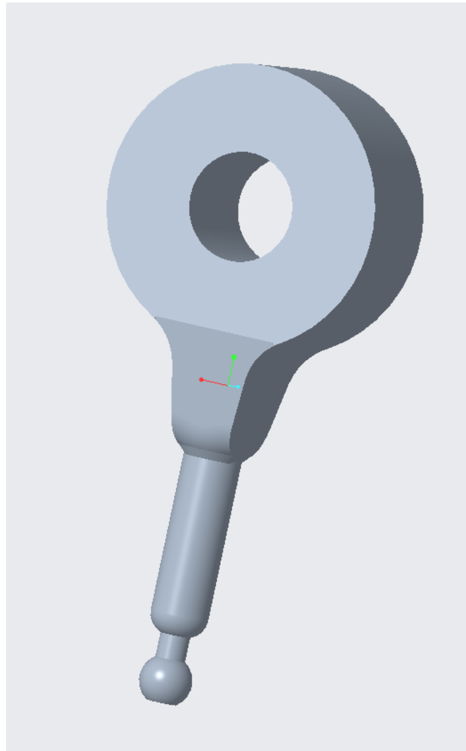
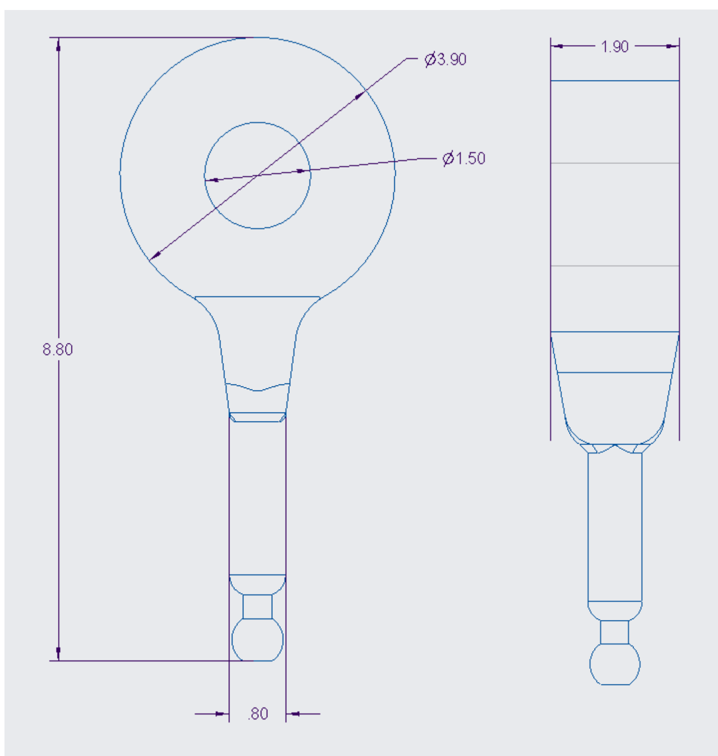


Figure 10: Primary Wobble Creo Part



Figures 11 and 12: Primary Wobble Drawings (Top & Side View)

A 3D rendering of the secondary wobble is shown in Figure 13. Again, a drawing was then created from this part showing part dimensions which is viewable in Figure 14. The secondary wobble is nearly identical to the primary wobble the only difference between the two being their respective heights. The thickness of the secondary wobble is identical to that of the primary wobble (1.9 cm), so a side view is not shown.

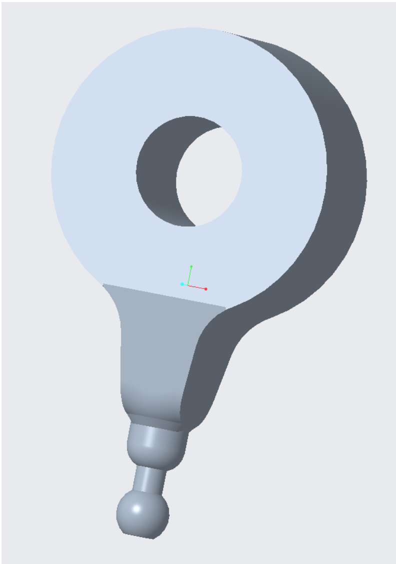


Figure 13: Secondary Wobble Creo Part

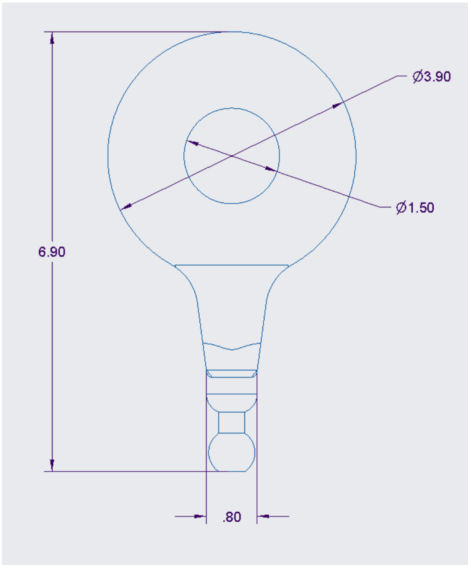


Figure 14: Secondary Wobble Drawing

3.2 SAWZALL WOBBLE SHAFT

A 3D representation of the wobble shaft was also recreated in CREO Parametric. Included in this representation is the peculiar 150^o angle which is key to the design of this fixture. Also, the hole passing straight through the shaft is included in the part. According to the technicians at Milwaukee Tool, the integrity of this hole passing through the shaft is incredibly important to the function of the tool and must not be compromised. This adds another incentive to create a fixture, as a fixture could help protect this hole from being damaged by the arbor press. A 3D rendering of the shaft part designed in CREO is shown in Figure 15.

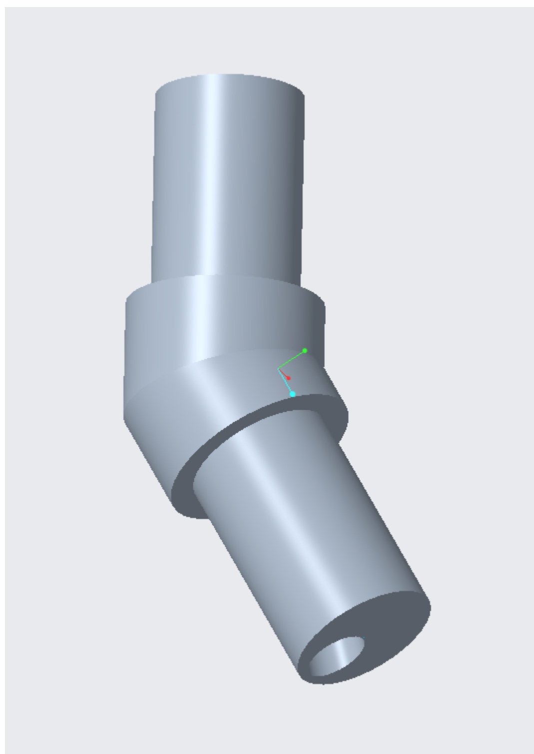


Figure 15: Wobble Shaft Creo Part

As with the wobbles, a drawing showing dimensions of the shaft was created. This drawing is shown in Figure 16.

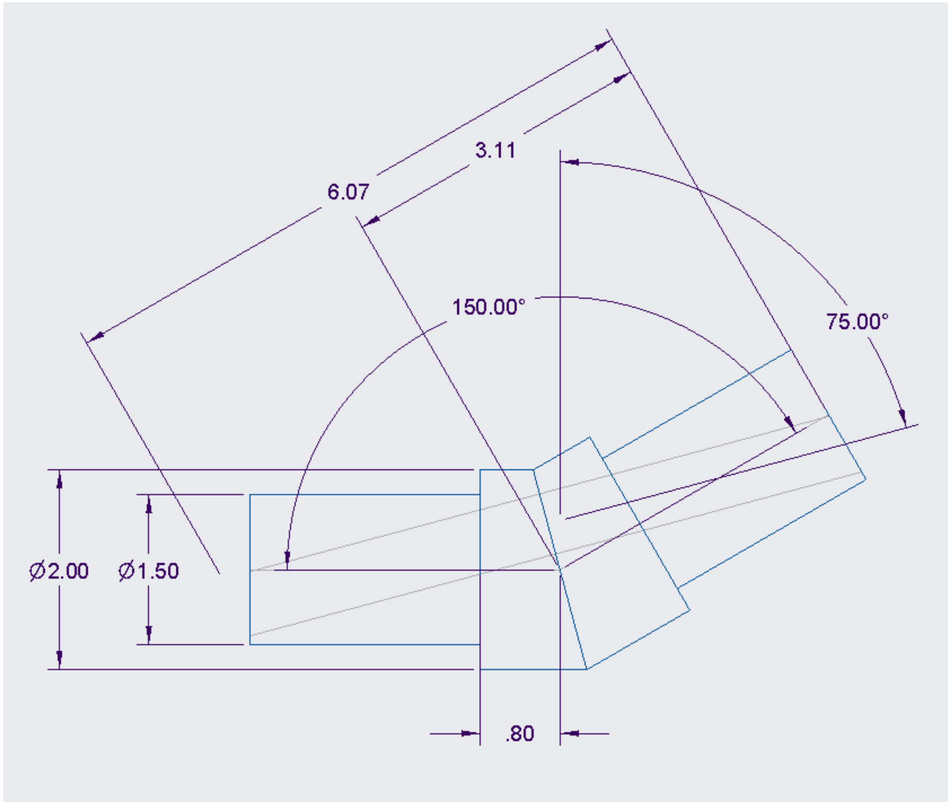


Figure 16: Wobble Shaft Drawing

By creating these parts in the CAD program CREO Parametric, it gave our design team an infinite sandbox in which to test concepts on these created parts. Additionally, it provided us with proper constraints via placing the dimensions we acquired on these created parts.

3.3 ARBOR PRESS

From measurements gathered during our sight visit we were able to create quantitative restraints for our fixture due to the limitations of the arbor press working area. Any fixture created was to be less than 16 inches in height to provide clearance under the press of the arbor press. Also, the fixture was required to be less than 18 inches in width and length due to the size of the platform upon which items are placed on the arbor press. Again, the press can produce a maximum of 8 tons of pressure, so any designed fixture would have to withstand such a load with continued ease. Similarly, the fixture would be required to be made of a stronger material than the wobbles, wobble shaft, and arbor press piece in order to prevent deformation and wear.

3.4 LIFESPAN OF FIXTURE

By request of the Milwaukee Tool quality engineers, the fixture was asked to have an "infinite" lifespan. In order to transform infinite into a quantitative number, we decided to give an estimated lifespan of 20+ years with servicing of the fixture approximately every 5 years. The fixture should be incredibly durable, reliable, and simple to use. Since the purpose of the fixture is to expedite the repairs process, simplicity of use should be at the forefront. Again, over 1100 Sawzalls were repaired in 2020; 2020 being a year with a sustained portion of economic shutdown due to the COVID-19 pandemic. For that reason, an even larger number than 1100 presses are to be expected during 2021 and into the future. Therefore, this fixture should be built to last.

4. PROJECT REPORT

Creation of a clear and concise problem statement along with a descriptive PDS concludes the first phase of the design process. Engineers can now use those documents as roadmap to the creation of concepts to solve the problems outlined in the problem statement following the parameters set in the PDS. The next steps of the design process involve creating a task list or outline as described in the design process overview, brainstorming and creating concepts into drawings, sketches, and CAD models, selecting a concept using a selection matrix, and formulating a DFMEA for the selected concept.

4.1 TASK LIST / OUTLINE

The full outline for our design team can be viewed in the Appendix [E]. In summary, the first task for all members of our team was to formulate design concepts. Once viable concepts were created by each member of the team, we had a meeting to compare and contrast the benefits and drawbacks of each design. Using a selection matrix, one specific design was decided upon. Once our team had a finalized design concept, each of us split into completing individual parts of the design. The table below summarizes which group members had which specific tasks leading up to the final design exhibition and presentation at the end of the semester.

Table 2: Task List

Group Member	Task
Tyler Moore	Detailed Creo Models, Drawings, and Animations / 3D - Printing
Ben Savino	Force Diagrams / DFMEA / Tri – Fold Poster Setup
Alejandro Sarabia	Bill of Materials / DFMEA / 3D - Printing

4.2 PRELIMINARY DESIGNS

In the brainstorming process of creating designs, our group spilt into two groups designing two viable options. Ben and Alejandro worked on creating a simple yet functional block fixture, while I approached the problem creating a clamp fixture containing multiple links. Both of these fixtures are explained in detail below.

4.2.1 BLOCK CONCEPT

One of the first design concepts generated by our group we dubbed the "block" concept. This fixture design was incredibly simple, as it essentially only contained a single block. The block was to have a shape of a wobble milled out of it in a fashion that would allow the wobble to be placed into the block like a puzzle piece. Within the milled wobble-shaped cavity would be another milled out hole with a diameter of 1.5 cm. This hole would serve the purpose of allowing space for the shaft to protrude into it once the wobble was pressed onto the shaft. The entire block would be made at an angle so that when one of the wobbles and the shaft was placed into it, the top of the shaft, and therefore the top wobble being pressed, would be level and flush with the arbor press in accordance with the problem statement. The required angle for the bottom of the block to allow the top of the shaft to be level was 30º. An early-stage sketch of this concept is shown in Figure 17.

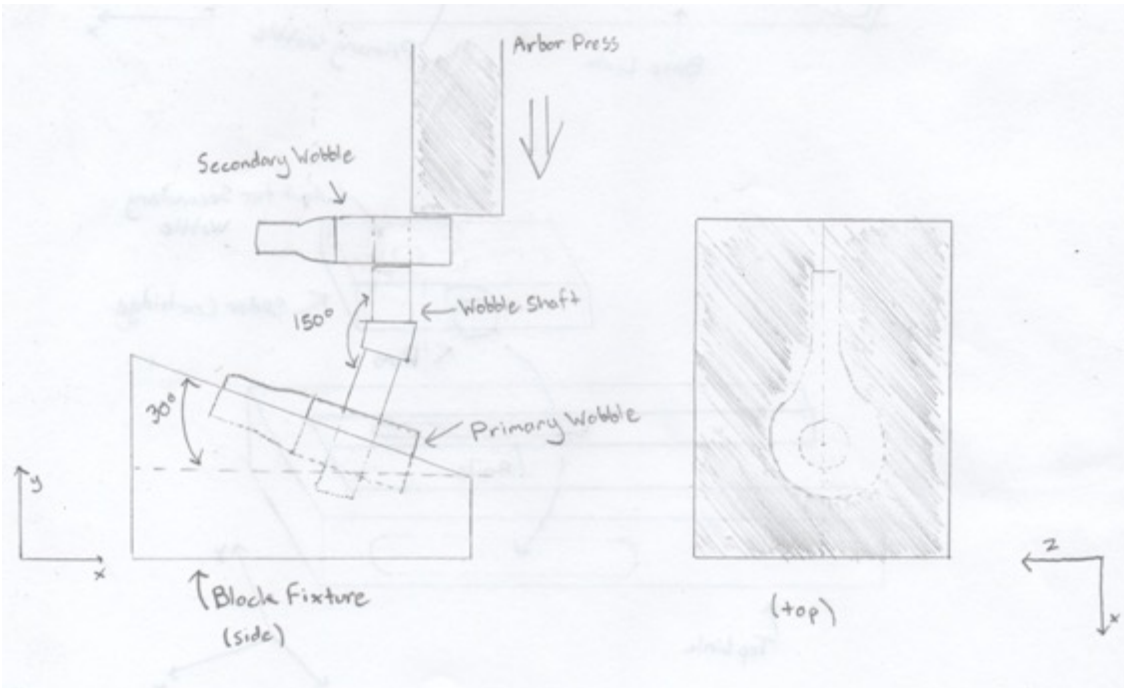


Figure 17: Block Fixture Concept Sketch

Alejandro, a member of our design team, produced a CAD sketch of this design and Creo Parametric, which can be seen in Figure 18.

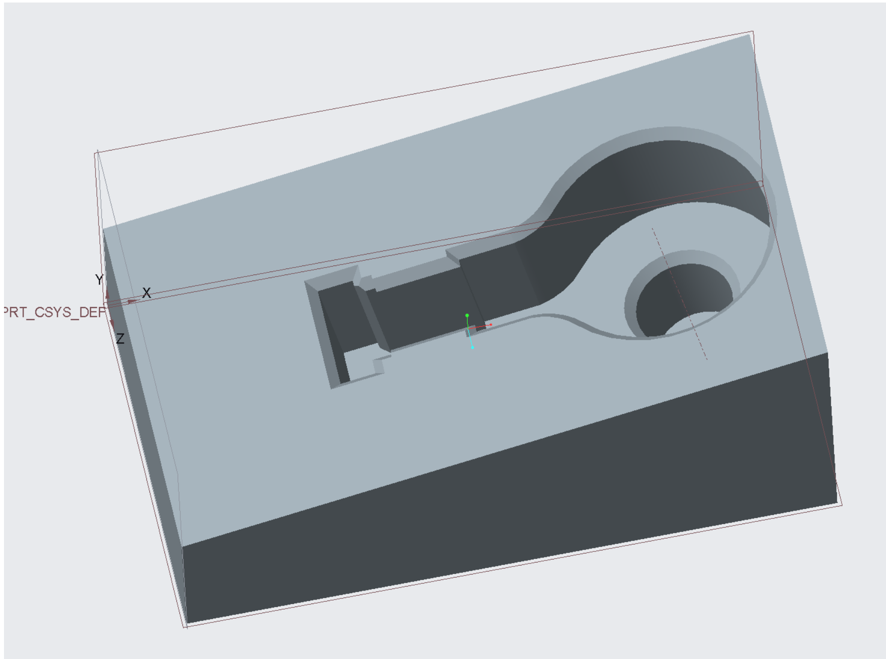


Figure 18: Block Fixture Creo Model

Additionally, our team produced a 3D printed prototype of this fixture using the facilities at the University of Mississippi library. A photo of this prototype can be seen in Figure 19.

Figure 19: Block Concept Prototype

Benefits of the block fixture include its simple design, ease of manufacturing, and ease of use. One drawback of the block fixture would be that the technician would still need to hold the wobble shaft while using the arbor press, as the wobble shaft can twist when it is loosely placed on the bearing. Another drawback would be the fact that the arbor press would still be applied directly to the wobble. This direct pressure runs the risk of damaging the wobble or damaging the hollowed hole in the wobble shaft which we were directly instructed not to allow.

4.2.2 CLAMP CONCEPT

Another fixture concept produced by our team was approached from a kinematics standpoint. We asked ourselves the question of if links were to be extended from two wobbles being pressed onto the wobble shaft, where exactly would they connect? After some brainstorming, we produced a rough sketch for a fixture that somewhat resembles a foot pedal for a bass drum. A base link with a milled-out slot for the primary wobble to rest in (similar to the block concept) was extended out in a length parallel to the primary wobble shaft. At the end of this link could be placed a hinge for the top link of the "pedal" to attach and rotate on. The top link would extend from this link back toward the wobble shaft but at an upward angle of 30º, allowing a milled-out slot for the secondary wobble to be placed in and be flush with the secondary wobble. The idea was that if the load from the arbor press was placed on the top link, the link would "clamp" and press the two wobbles onto the wobble shaft. The clamp could then be opened and reset to apply another set of parts. The "clamping" motion of this fixture earned it the nickname of the clamp concept. A rough preliminary sketch of the clamp concept is viewable in Figure 20.

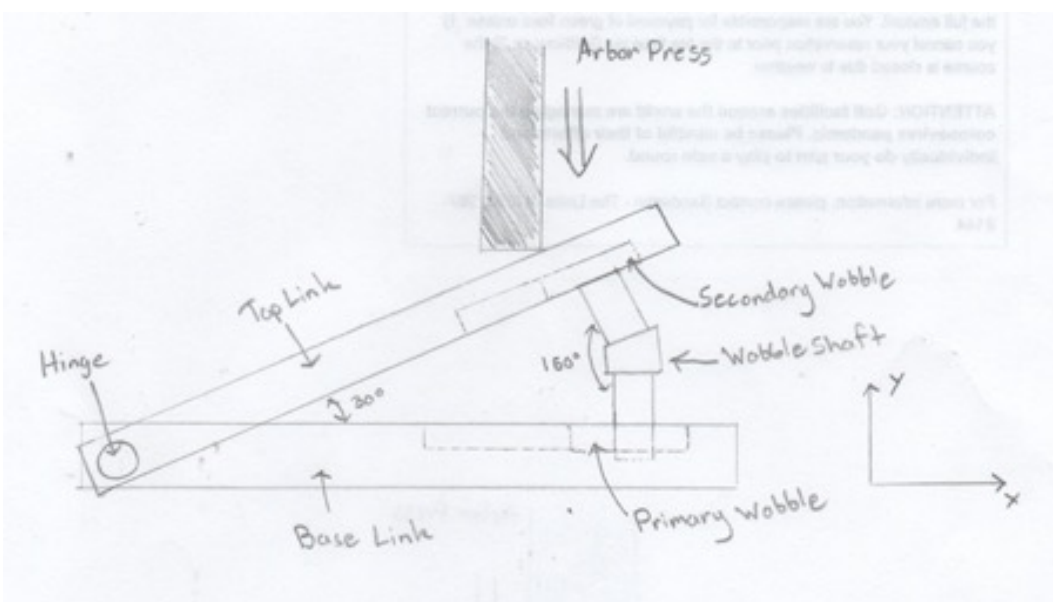


Figure 20: Clamp Fixture Concept Sketch

In order to obtain a better understanding of how this fixture would work in 3D, a model of the clamp fixture was created in Creo Parametric to house the primary wobble, secondary wobble, and wobble shaft models shown in the PDS section. Prior to creating this preliminary model, our group understood that the effective length of the top link would become shorter as the wobbles were pressed onto the shaft. For this reason, instead of milling a hole for the shaft to be pressed into similarly to the bottom link, we created a slot of the same diameter as the wobble shaft to allow the secondary wobble to "slide" down the top link as it was pressed onto the shaft. This slot can be seen on the top link in the exploded view of the preliminary clamp fixture concept shown in Figure 21.

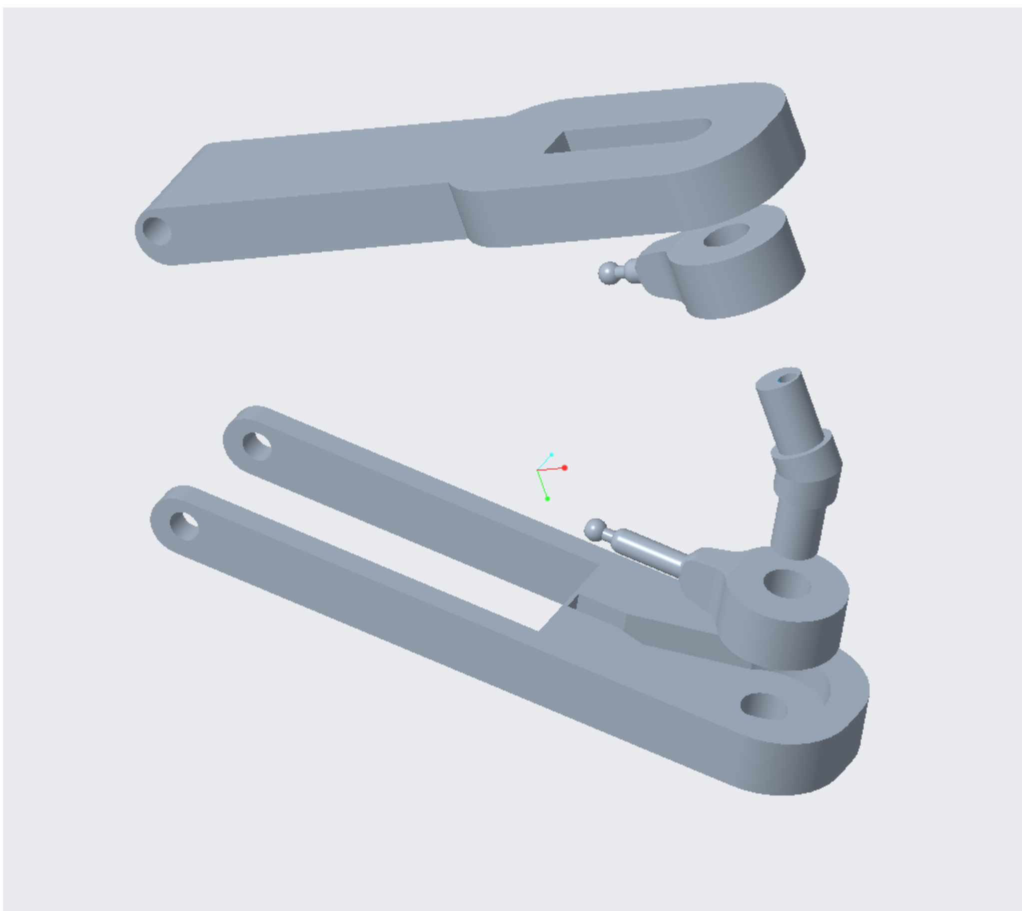


Figure 21: Preliminary Clamp Fixture Creo Model

Once this model was created, another flaw within the clamp concept was noticed. Not only does the effective length of the top link shorten as the clamp is pressed, the angle of the top link changes as well. During a press, the angle of the top link decreases from 30° while the angle of the secondary wobble being pressed onto the shape maintains a constant 30° from parallel. The clamp fixture still had promise as a viable option, but this problem needed to be addressed. After a number of brainstorming meetings amongst team members as well as a conference with a machine shop technician, a solution to the problem was formulated. A cartridge housing the secondary wobble could be equipped with pins that would ride on rails within the top link. This would allow the effective length of the top link to change as needed during the press while simultaneously keeping the applied force on the secondary wobble flush with the wobble shaft. A preliminary sketch of the slider concept is shown here in Figure 22.

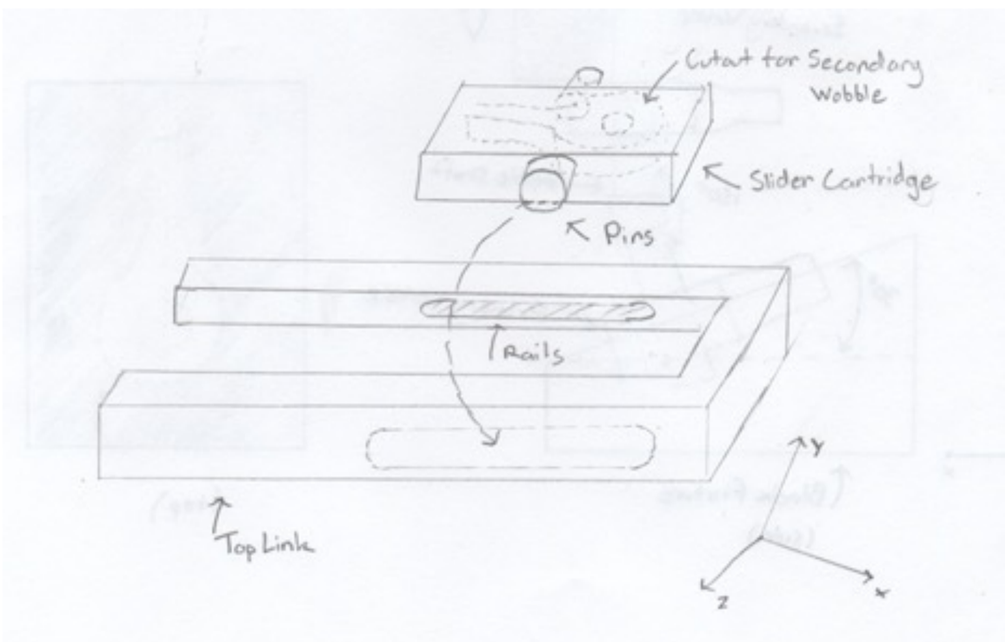


Figure 22: Slider Concept Preliminary Sketch

The introduction of the slider to the clamp fixture design allowed the clamp to work as desired. The last necessary addition to the clamp fixture concept was a place for the load of the arbor press to be applied. A platform was added above the top link at yet another 30^o angle. The load from the arbor press would be applied directly to this platform, clamping the fixture and pressing the primary and secondary wobbles onto the wobble shaft. Some benefits of the clamp fixture include an ability to press both wobbles onto the wobble shaft without the technician having to hold the shaft or any moving parts. Additionally, the force of the arbor press would not be placed directly onto any of the working parts. A drawback of the clamp fixture design would be its comparably complicated design for manufacturing purposes as it has multiple moving parts.

4.2.3 DECISION MATRIX

The decision matrix used by our design team was a Pugh Selection Matrix. Pugh selection matrices work by comparing potential design concepts directly. Various selection criteria are given weights based upon importance, then each design concept is scored on how they complete that criteria. For example, if a selected criterion was given a weighted importance of 6 out of 6, and a design concept scored a 7 out of 10 on that criteria, the selected concept would be given a total score of 42. Scores for each criterion are added, and the concept with the highest total score is selected. The Pugh Selection Matrix used by our design team can be viewed in its entirety in Appendix [C].

4.3 DESIGN SELECTION

Using the criteria described in the decision matrix our group decided to move forward with the clamp fixture concept. The clamp fixture allows technicians to simply place working parts into their respective slots and clamp the fixture in one fluid motion of the arbor press. Technicians would not have to hold the shaft using the clamp fixture as they would using the current method or the block concept, and no force is applied directly to the wobbles or shaft.

4.4 DETAILED DRAWINGS

Drawings of the assembly created in Creo Parametric were key in the design of this clamping fixture. Creo Parametric allowed us to animate the motion of the fixture pressing the primary and secondary wobbles onto the wobble shaft, helping with visualization and application into the real world. This section includes figures of the assembly in its entirety in the “pre-press” and “post-press” position, drawings of the assembly, as well as drawings showing the dimensions of the individual parts that make up the assembly. The final fixture as a whole is only made up of 3 parts: the base, the top, and the slider. An additional 1 cm diameter bolt with a length of at least 11 cm is required to create the hinge. The clamping fixture in its entirety in the “pre-press” position can be seen in Figure 23 and the “post-press” position in Figure 24. In addition to the figures of the two pressing positions, an exploded view of the fixture including the primary wobble, secondary wobble, and wobble shaft can be view in Figure 25 along with a 2D drawing view of the fixture in Figure 26.

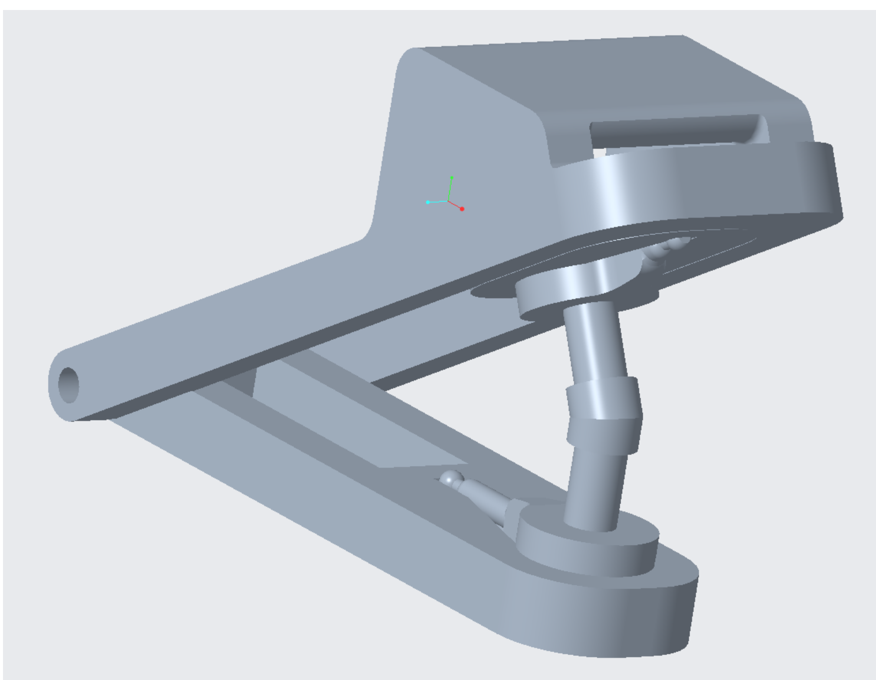


Figure 23: Clamp Fixture Pre-Press Creo Model

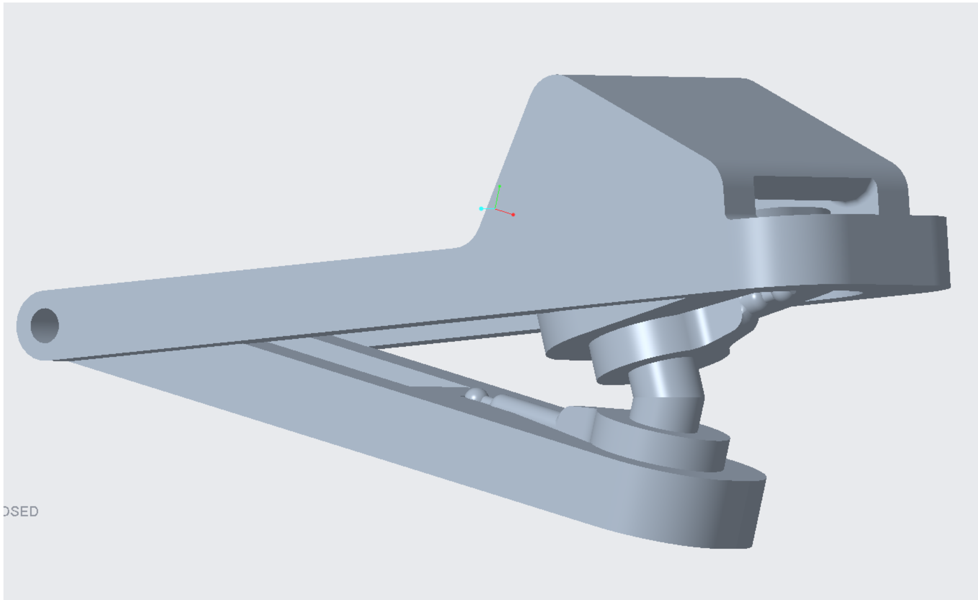


Figure 24: Clamp Fixture Post-Press Creo Model

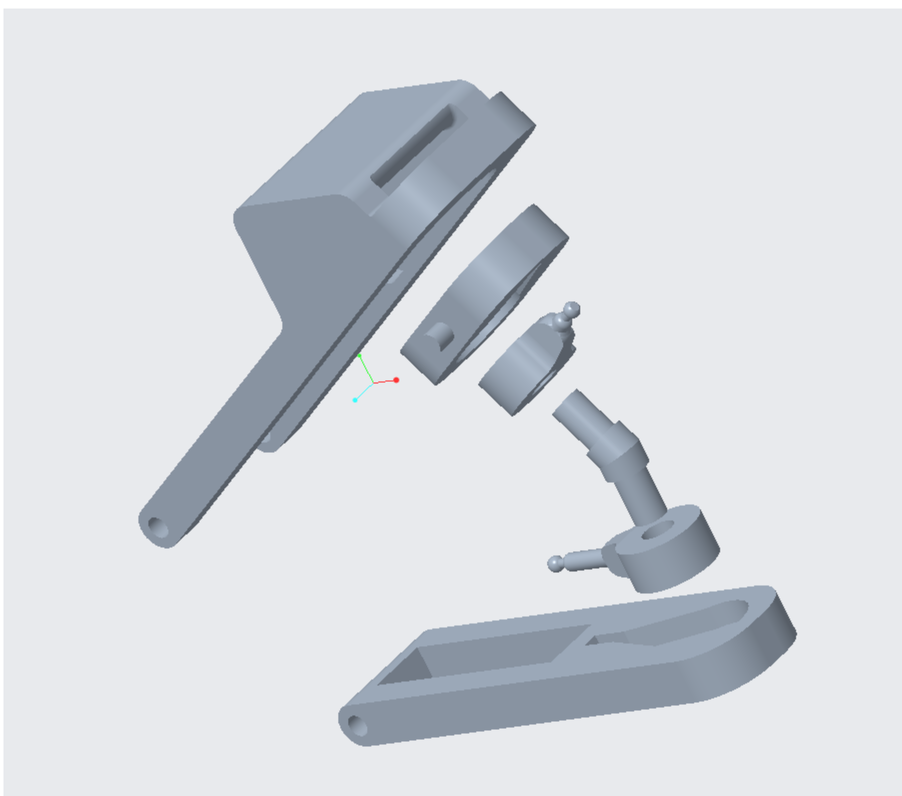


Figure 25: Clamp Fixture Exploded View Creo

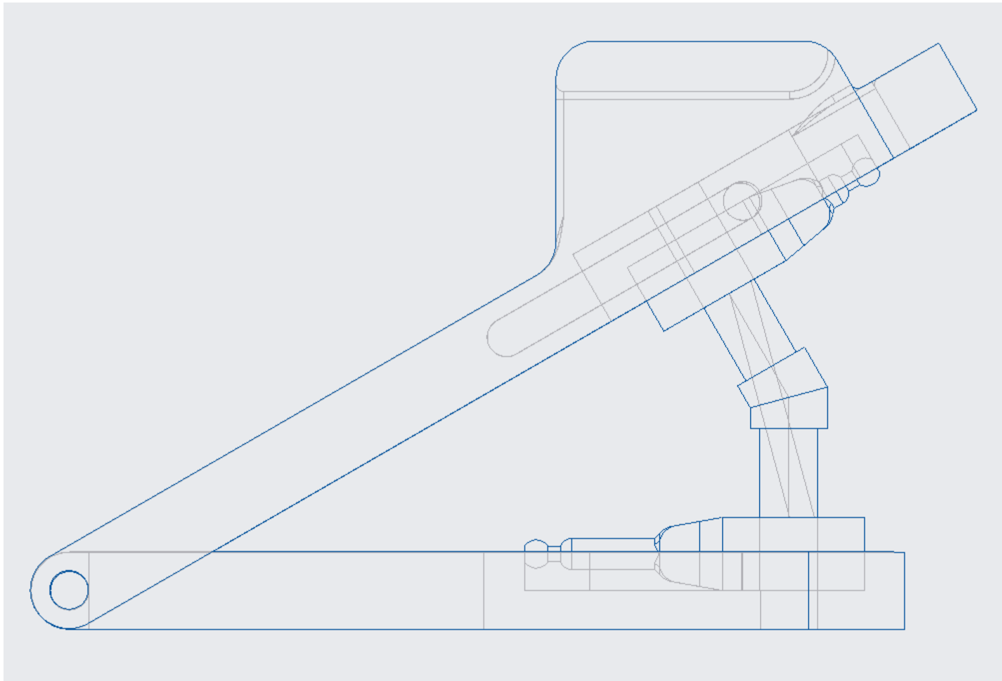


Figure 26: Clamp Fixture Drawing

Figures 29, 30, and 31 show the dimensional drawings and an isometric view of the base part, the top part, and the slider part, respectfully. Again, all dimensions are in centimeters. These Creo Parametric files can be shared with manufacturers and other CAD users to create 3D prints, tweak any necessary adjustments, and provide a blueprint for how exactly to machine and build this fixture.

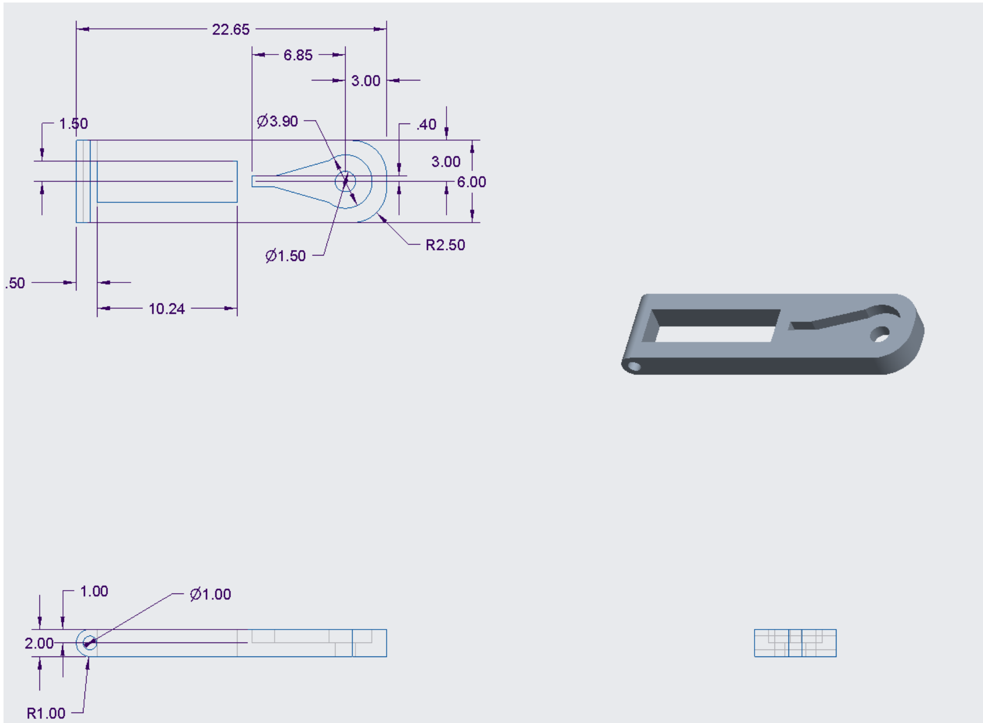


Figure 27: Base Part

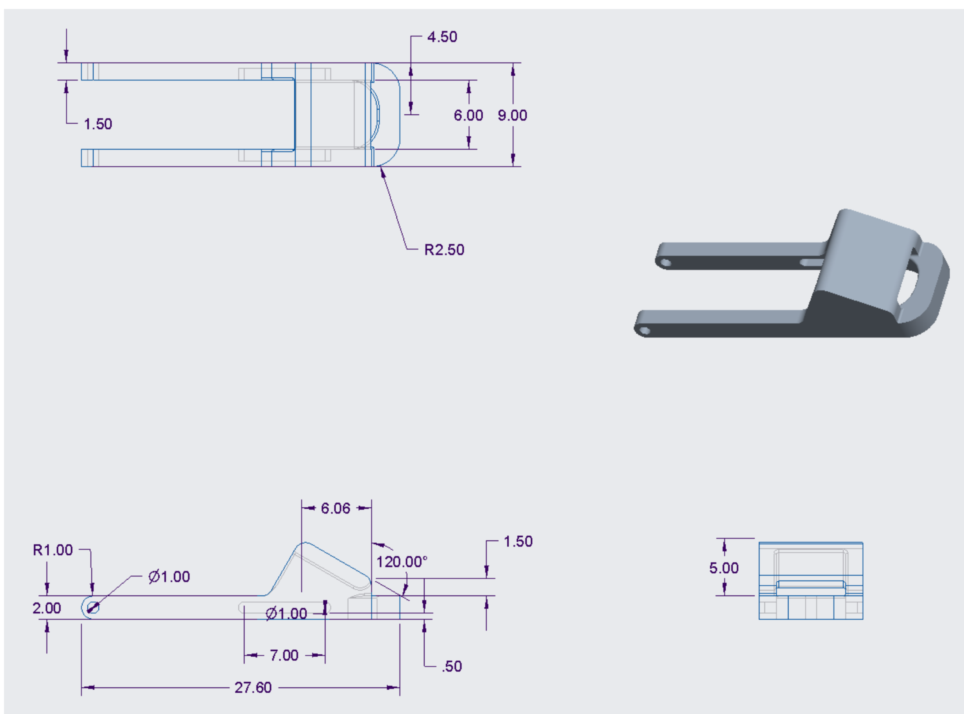


Figure 28: Top Part

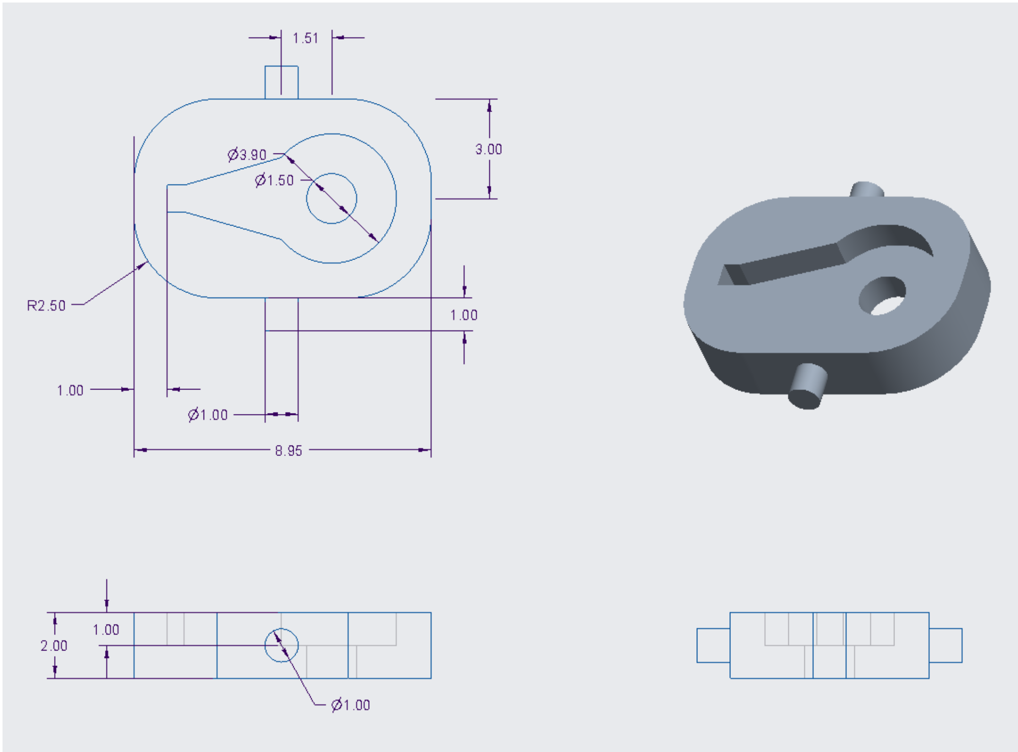


Figure 29: Slider Part

4.5 MATERIAL SELECTION

A desired material to create this fixture would be strong enough to absorb the stress provided by the arbor press without damaging the arbor press or the parts being repaired. Additionally, the material would be required to be easily machinable due to the unique shapes of the connecting parts. Finally, the fixture should maintain a low cost. For these reasons, 17-4 Stainless Steel was selected as an ideal material to produce this fixture. 17-4 Stainless Steel provides high strength, good corrosion resistance, and is able to be machined with ease. Costing only $0.40 a pound, cost of the overall fixture can stay at a minimum. [5] For the case of the pins and bolt to hold the moving parts of the fixture together, standardized parts can be identified. The identification of standardized parts will be described in a later section.

4.6 DFMEA

A DFMEA document, or Design Failure Mode Effects and Analysis document, is essential to an engineering process. [6] Within a DFMEA, product components and their functions are listed within a spreadsheet. For each component of the design, potential modes of failure are brainstormed and analyzed. Each potential mode of failure is assigned a severity score, similarly to the Pugh Selection Matrix described in section 4.2.3. Scores of probabilities and how determinable the failure is are also given. A probability score describes the likelihood of a failure occurring, and the determinable score describes how identifiable the failure would be. By contemplating the various ways in which a part could fail, steps can be made to engineer and design around such a failure. The DFMEA helped our design team provide solutions to problems given the problem statement, such as a method of protecting the bearings and shaft from damage using the clamp fixture. The full DFMEA for our design can be seen in Appendix [D].

4.7 COST ANALYSIS

In order to fully analyze the cost of creating this fixture, a bill of materials is required. A bill of materials is a list of the raw materials, components, and parts needed to assemble a full product. Essentially, the bill of materials provides a list of ingredients in order to cook a recipe. From viewing a bill of materials, an engineer can seek out the most cost-efficient options to fill listed part requirements.

4.7.1 BILL OF MATERIALS (BOM)

An estimated bill of materials required to assemble our designed clamp fixture is located in Table 3. The baseplate, top connecting link, and slider pieces would all require custom machining which would increase their base cost due to labor. The pin and bolt with a nut are standardized parts. Standardized parts are desirable as they require no manual labor, and they are easily replaceable if a part becomes damaged.

Table 3: Bill of Materials

ITEM	MATERIAL	QUANTITY	COST
Baseplate	17-4 Stainless Steel	1	$0.40 / lb
Top Connecting Link	17-4 Stainless Steel	1	$0.40 / lb
Slider	17-4 Stainless Steel	1	$0.40 / lb
Pin	Alloy Steel	2	$36.75 (per 10)
Bolt w/ Nut	A-2 Stainless Steel	1	$2.50 Total

4.8 SAFETY

When using the fixture, technicians must make sure to keep their fingers clear of any pinch points within the fixture before pressing the arbor press down on the clamp. Besides that, use of this fixture is intended to be safer than the prior method of applying the wobbles onto the wobble shaft. Instead of having to physically hold the wobble shaft with one hand while pressing down on the arbor press crank with the other, technicians can now just hold the base of the fixture with their hand far away from the pressing load of the arbor press. Where before there was a risk of slipping while pressing onto an angled wobble, now there is a safe, simple press onto the clamping fixture itself.

5. IDENTIFYING STANDARDIZED PARTS

As described in the detailed drawing and bill of materials sections, a bolt with a maximum diameter of 1 cm and a minimum length of 11 cm is required for the hinge connection between the base and top pieces. Ideally, this bolt would produce a clearance fit which would allow the hinge to rotate with little resistance. A suitable metric hex bolt made of stainless steel 18-8 (A-2) was identified, possessing a length of 110 mm and a diameter of 10 mm. This bolt is available for $2.22 each online from Bolt Depot [8]. A matching metric hex nut was also identified, also made of stainless steel 18-8 (A-2) available for $0.28 each from the same distributor. [9] Standardized alloy steel pins were also found that possessed the proper diameter, available for $36.75 from another steel manufacturer. [10]

6. PROTOTYPE DISPLAY

On April 20, 2021, our design team presented A 3D printed prototype along with our tri-fold poster board describing our design process. For approximately four hours, our group explained our project to those attending our exhibit and fielded any questions they may have had. Spectators at this exhibition included University of Mississippi faculty and industry professionals from the area. A 3D printed model was printed at a scale of 0.5 due to size constraints of the printing tray. Our tri-fold posterboard is viewable in Figure 32 along with an image of the 3D printed prototype in Figure 33. The poster board presentation included many of the design aspects discussed in this thesis, including the problem statement, photos of the wobbles and wobble shaft, Creo models of the selected clamp concept, dimensioned drawings of the parts, and a bill of materials. This exhibition tested our groups professional skills by putting on display how well we were able to verbally explain our design process and analysis in simple terms.

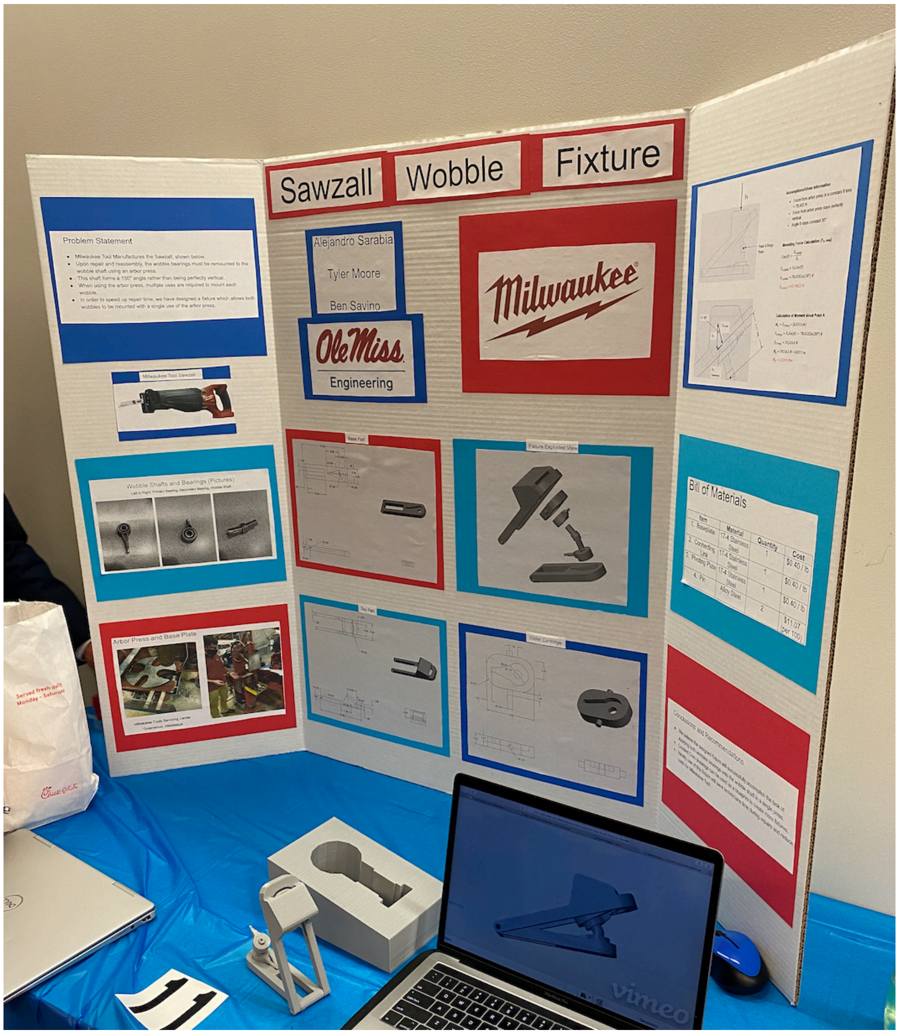


Figure 30: Poster Board Presentation

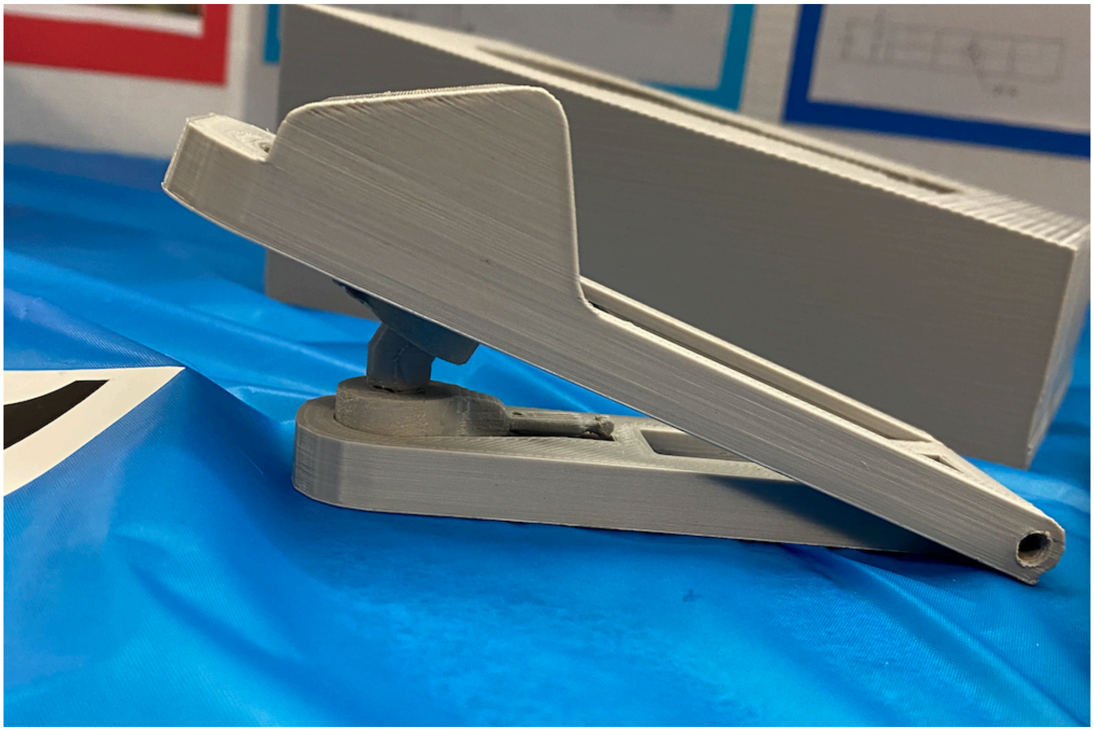


Figure 31: 3D Printed Prototype

7. FULL WORKING MODEL / FUTURE WORK

Due to time constraints of the spring semester, a full working model of the clamp fixture was never produced. Although it was not made at the time of creating this thesis, our group believes that a full working model of our designed clamp fixture could be utilized with great success. Applying the dimensions given in the CAD drawings to a steel working model would house the wobbles perfectly, allowing them to be pressed onto the shaft completely with one application of the arbor press. Perhaps after the publication of this thesis, our design team will have time to create a fully functioning model of the fixture clamp

8. CONCLUSIONS

In order to assess the success of our design project, we must take one last look back at our problem statement. Our mandate from Milwaukee Tool was to produce a fixture that would allow a Sawzall technician to press both the primary wobble and secondary wobble onto the 150^{o} angled wobble shaft in a single use of the arbor press during repairs. Compared to the current method of repair requiring multiple uses of the arbor press, this fixture would expedite the repairs process allowing Milwaukee Tool to repair more Sawzalls in a workday, saving them both time and expenses. The clamp fixture is simple and safe to use for the technician. When in use, the clamp fixture keeps both the primary and secondary wobbles flush with the wobble shaft throughout the press. This fluid motion allows both wobbles to be pressed onto the shaft with one use of the arbor press. Through a well-documented engineering design process, we are confident that our design team produced a prototype in the clamp fixture that provides a solution for the problem stated in the problem statement.

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[6] Pandya, Tejas. "Purpose of DFMEA (Design Failure Mode Effects Analysis)". The University of Mississippi, 2021.

[7] "What is a Bill of materials and how to make one: A Complete Guide". Katana. (n.d.). [Online]. Available: https://katanamrp.com/blog/bill-of-materials/. [Accessed Apr-2021]

[8] Metric hex bolts, stainless STEEL 18-8 (A-2), 10mm X 1.5MM x 110mm. (n.d.). Retrieved April 29, 2021, from https://www.boltdepot.com/Product-Details.aspx?product=5844

[9] Metric hex nuts, stainless STEEL 18-8 (A-2), 10mm X 1.5mm. (n.d.). Retrieved April 29, 2021, from https://www.boltdepot.com/Product-Details.aspx?product=4779

[10] Dowel pin, Press Fit, hardened GROUND, stainless Steel, PLAIN, 10.007 TO 10.018 mm pin dia. (n.d.). Retrieved April 29, 2021, from https://www.grainger.com/product/GRAINGER-APPROVED-Dowel-Pin-5EDK5

APPENDIX

[A]

Sawzall Wobble Fixture Questionnaire

Team Members:

- Ben Savino
- Alejandro Sarabia
- Tyler Moore

List of potential questions to ask Milwaukee Tools while visiting to capture the VOC:

- Material Questions
    - What type of material should the sawzall wobble fixture be/how strong should it be?
    - What is the desired lifetime for the sawzall wobble fixture?
    - What materials are the sawzall wobbles/shafts made of?
- Intended Placement Questions
    - Should the fixture be mobile or a permanent fixture?
    - Should the fixture be applicable to other uses or specific to the sawzall wobble?
    - Where exactly does the arbor press place force on the sawzall wobble/or their shafts?
    - What are the dimensions of the arbor press?
    - What are the dimensions of the base of the arbor press that this fixture is intended to be attached to?
- Questions for the Sawzall Technicians
    - How many sawzalls do you typically fix in a workday?
    - How long does it typically take to place the sawzall wobbles on their shaft?
    - What is the biggest complaint you have with the current way sawzall wobbles are placed on the shaft?
    - Are there any limitations to where this fixture could be placed?
    - Are there any safety requirements that come along with using the arbor press?
    - Is there a feature that a sawzall wobble fixture could include to help with any safety issues?
- Questions for the Head Engineers/Milwaukee Tools
    - What are your overall requirements for this fixture?
    - Should this fixture be intuitive, or should it come with very specific instructions for the technicians on how to use this fixture?
    - When is this device due/is there a timeline for this device?
    - How many tools are fixed annually at this factory?
- Sawzall Wobble Questions
    - What are the dimensions of the sawzall wobbles?
    - What are the dimensions of the sawzall shaft?
    - What is the angle of the sawzall shaft?
    - How much force is required to press the wobble on the shaft?
    - Can the wobbles be removed from the shaft? If so, should this fixture help with being able to take the wobble off the shaft

[B]

Product Design Specification: Sawzall Wobble Fixture
Created Date: 2/17/2021

Group Members:

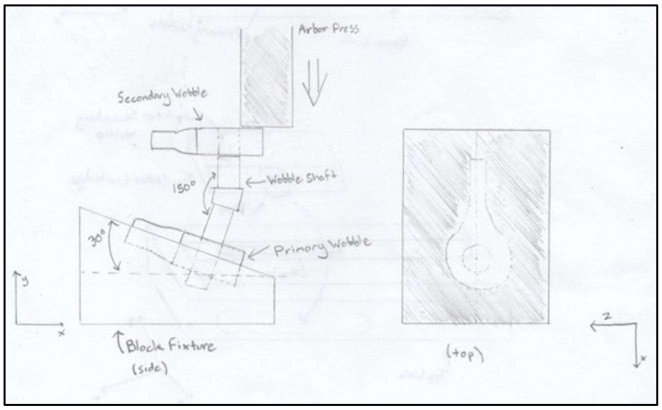
- Alejandro Sarabia
- Tyler Moore
- Ben Savino

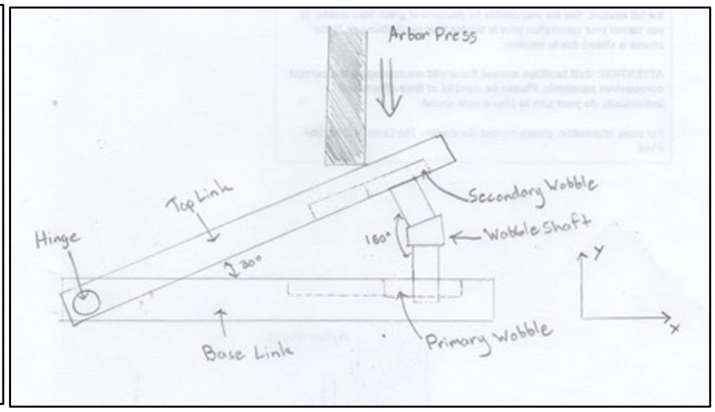
A. Purpose
    a. Reduce the amount presses required to mount a Sawzall Wobble on the Wobble Shaft by creating a fixture that makes the wobble flush with the arbor press
    b. This is to reduces the overall time to mount the wobbles, allowing more wobble repairs and reducing costs
B. Features
    a. Ease of maneuverability - technicians move fixtures to wherever is comfortable for them
    b. Durable - maximize lifespan
    c. Ease of use - many uses per day
    d. Stronger material than the wobbles - can't deform/wear
    e. Must hold the wobble flush with the arbor press
    f. Must allow for a single arbor press to mount both the primary and secondary wobble on the shaft
C. Competition
    a. Not-applicable, this design is specifically requested by Milwaukee Tool, it is not known to be used elsewhere.
    b. The time at which wobbles can be mounted on the wobble shaft is used for comparison instead of competitive brands/parts.
D. Intended Market
    a. This product is required for Milwaukee Tools Servicing Center in Greenwood, Mississippi. Additional parts may be required for a new repair shop in Greenwood, Indiana.
E. Performance Requirements
    a. Less than 18 inches in width & length
    b. Less than 16 inches in height
    c. Must withstand ~8 tons of pressure
    d. Must withstand over 1100 presses per year (judging off 2020 calendar year)
F. Life-cycle
    a. Life cycle of the product is estimated for 20 years of use
    b. Servicing of part should be checked every five years
G. Human Factors
    a. Ease of placement of shaft in fixture
    b. Safety for technician use
H. Social, Political, Legal and Ethical Issues
    a. Not Applicable, intended for the use of Milwaukee Tools

I. Quantity
    a. Two fixtures need to be kept with each arbor press used in the shop

[C]

Sawzall Wobble Fixture Pugh Selection Matrix





Design 1: Wedged Block Fixture

Design 2: Clamping Fixture

Pugh Selection Matrix

Criteria	**Weight**	**Design 1 Score**	**Design 2 Score**
Ease of use	5	7	5
Constrains pieces for consistent mounting	3	2	10
Maneuverability	4	8	7
Lifespan	6	9	6
Protection of bearings and shaft	6	1	9
Safety of technicians	4	1	9
Ease of manufacturing	2	8	7
Cost	1	5	5
Weighted Total		158	228

* Weights vary 1 to 6, 1 being least important, 6 being most important. Scores vary 1 to 10, 1 being least satisfactory, 10 being perfectly satisfactory.

[D]

System	Design Verification Process	**Potential**	FMEA Number	Project III
Subsystem		**Failure Mode and Effects Analysis**	Prepared By	Ben Savino
Component	Sawzall Wobble Fixture	**(Design FMEA)**	FMEA Date	2/20/2021
Design Lead		Key Date	Revision Date	4/15/2021
Core Team	Tyler Moore, Alejandro Sarabia, Ben Savino		Page	

Item/Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)	Responsibility & Target Complettion Date	Actions Taken	New Sev	New Prob	New Det	New RPN
Hinge/Hinge Pins	Excessive wear	Clamp loses range of motion, proper force cannot be applied	4	Lack of lubrication, excessive use, improper pin instalation	3	Lubricate fixture hinge on a daily basis, replace worn pins as needed	1	12	Choose wear proof material for manufacturing, ensure proper assembly						
Top Link	Damage from arbor press	None initially, may need replacement if wear is extreme	1	Excessive use	1	Choose proper material for fabrication	1	1	None currently needed						
Base Plate	Wear	None initially, may need replacement if wear is extreme	1	Excessive use	1	Choose proper material for fabrication	1	1	None currently needed						
Force Application to Bearing	Force applied at improper angle to shaft, effective length of top link does not decrease	Damage to shaft, bearing, fixture, unable to mount bearings	7	Inability of rotation/sliding, lack of lubrication, wear of top plate	4	Include slot on top link to allow for length change	7	196	Determine a way to maintain constant force direction axially along top portion of wobble shaft	4/14/2021	Introduce a nother plate component, allow plate to swivel and slide on pins to allow for length change while maintaining angle	2	1	2	4
Swiveling and Plate	Plate is unable to swivel or slide properly	Damage to shaft, bearing, fixture, unable to mount bearings	7	Wear of pins, wear of pin slots, unlubricated	1	Ensure proper and frequent lubrication	1	7	None currently needed						
Orientation of Wobble Shaft	Shaft rotates out of position, changes force angle required	Damage to shaft, bearing, fixture, unable to mount bearings	7	No rotational control of shaft other than technicians hand	3	Maintain proper bearing orientation, hold shaft in needed place	3	63	Find way to constrain wobble shaft to proper orientation with respect to top plate	4/14/2021	Add spring lodad pins to top plate and swiveling plate. Pins release when vertical bore through shaft is in proper orientation	2	1	1	2
Bearing Placement	Top bearing is able to rotate freely about wobble shaft	Technicians hands vounerable to pinching if required to manually hold top beraing	8	Top bearing is not constrained in any way	2	Technician holds bearing in palce until mounted	2	56	Constrain top bearing so it cannot rotate/move, reduce risk/uncertainty for technician	4/20/2021	Machine bearing shape out of rotating plate, allowing the technician to feel when bearing is in place and no longer needs to hold bearing thorugh press	3	2	1	6
Shaft Protection	Wobble shaft damaged when bearings are pressed on	Shaft damaged, must be replaced, slows repair time	7	Contact between arbor press and wobble shaft	4	Machine out shape of bearing in top and bottom plates	3	84	Ensure wobble shaft is protected/will not be contacted by press	4/14/2021	Create platform on top link designated for arbor press contact	2	1	1	2
Force Application from Arbor Press	Technician hand in mounting zone or press platform when press applied, force applied on parts causes rapid breakage of parts	Injury to technician	8	Improper force application direction, improper use of fixture	2	designed so that minimal human contact is necessary once bearings and shaft are in place as they are fully constrained	1	16	None currently needed						

[E]

Senior Design Project Work Log	**Date Performed**	**Group Member Performed**
Form Group	1/20/2021	All
Capstone Project Selection	1/21/2021	All
Setup Meeting with Milwaukee Tools	1/21/2021	All
Virtual meeting with Milwaukee Tools engineers	1/27/2021	All
Site Visit at Milwaukee Tools Servicing Center in Greenwood, MS	2/4/2021	All
Receive measurements and spare parts used to analyze project	2/4/2021	All
Create Questionnaire for Project	2/17/2021	All
Create Product Design Specifications	2/17/2021	All
Brainstorm and sketch initial design options	2/21/2021	Design 1: Alejandro, Ben Design 2: Tyler
Create selection matrix	2/25/2021	Ben
Decide on desired design	3/10/2021	All

Create DFMEA	4/1/2021	Ben
Meet with Matt Lowe to discuss project possibilities	4/6/2021	All
Design initial options on CREO	4/12/2021	Tyler, Alejandro
Revise models with Matt Lowe	4/13/2021	All
Get CREO designs 3D printed for presentations	4/14/2021	Tyler, Alejandro
Create bill of materials	4/14/2021	Alejandro
Discuss with Matt Lowe poster board setup	4/15/2021	All
Create tri-fold poster board for presentations	4/16/2021	All
Present project to Mechanical Engineering Department and guests	4/20/2021	All
Write up Design Project Report	4/25-29/2021	All

[F]

Project Title	Sawzall Wobble Fixture			
Students	Tyler Moore	Alejandro Sarabia	Benjamin Savino	
Mechanical Systems	This project was a strictly mechanical system			
Thermal Systems				
Both				
Multiple Constraints				
Aesthetics	N/a			
Cost	Cost was not important to Milwaukee Tool, as only two parts were required to be fabricated.			
Ergonomics	Ergonomics was considered for technician safety.			
Functionality	Functionality was the main goal of this project.			
Legal considerations	N/a			
Maintainability	This fixture was made of materials to have a maximum life span and require little maitnence.			
Manufacturability	This fixture can be easily manufactured and machined.			
Marketability	N/a			
Regulations	N/a			
Sustainability	N/a			
Ease of use	This fixture was designed to improve the ease of mounting two bearings, so ease of use was necessary.			
Others	N/a			
Appropriate Standards				
Engg Standard	N/a			
Process elements				
Identifying opportunities	Dr. Pandya provided our group with this opportunity with Milwaukee Tool.			
Developing Product Design Specification (PDS)	PDS was configured to guide the remaining tasks.			
Performing analysis and synthesis	Kinematic analysis and synthesis was completed primarily using CREO Software.			
Generating multiple solutions	Yes, two initial designs were generated.			
Evaluating solutions	Designes were evaluated using the Pugh Selection Matrix.			
Considering risks	Risks, while minimal, were determined through the DFMEA.			
Making trade-offs	N/a			
Based on earlier coursework				
Course	M E 541			
Course	M E 426			
Course	M E 324			