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CHAD FOR TOILETS

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ABSTRACT

All public facilities must provide handicap accessible restrooms in order to be compliant with current ADA requirements. Unfortunately, wheelchair users with little to no lower body mobility still encounter issues when using designated handicapped facilities. Users currently experience instability while using the current toilets and have trouble transferring to and from their wheelchair. To alleviate some of the issue's users are facing, our team looked to expand on work done by previous MSD teams to create a functional device that fits over existing toilets. The designed device can lift and lower the toilet seat to the height of the wheelchair to ease the transfer process and provide support for users to utilize during the restroom process. The team was able to design a functional prototype of the device, however, based on the current size of the hydraulic cylinders, the device can only accommodate lifting for individuals up to 180 lbs. The current prototype shows the device is sturdy and provides needed additional supportive features, and future work should be conducted to improve weight capacity of the lift and to improve the overall visual appearance of the device.

BACKGROUND

Public restroom facilities are required to accommodate everyone, most importantly individuals who are challenged with the current bathroom process. Articulating Toilets are used to accommodate individuals who are required to use wheelchairs for daily transportation and have little to no use of their lower body. The toilet itself should provide the user with the ability to use the restroom in a timely and efficient manner. However, some people are still encountering problems while using wheelchair accessible restrooms. Some of these daily problems include not having the means or strength to lift themselves onto the toilet seats, experiencing a difference in height between the toilets and the wheelchair, and not having enough room to clean themselves after use.

To gain more understanding about the purpose of our device, we conducted an interview with our client Art North. Art's son uses a wheelchair to move around and has trouble with the current bathroom setup. Some of the challenges Art highlighted for the current restroom setup included, little access to clean oneself after use, the lack of arm support, and that the support bar on the wall is too far away from the toilet for wheelchair users to actually utilize during transfer. Additionally, he highlighted how wheelchair users can have limited to no torso strength or use of their legs. These combined challenges can cause the restroom process to take anywhere from 30 to 45 minutes in a public space. It is important for the user to have privacy and the ability to use the restroom independently, however, this is not feasible for some users with the current setup. The interview with Art helped the team understand the full problem and the environment the designed device will be operating in.

The interview with Art also helped the team understand the customer requirements and why some are more important than others. The customer requirements for this project correspond to the creation of a device that can fit

into current restroom facilities that alleviates some of the issue's wheelchair users are facing. Some of the more important customer requirements for the device include better access for cleaning oneself, additional supportive features, ability to ease transfer without touching the toilet seat, users are able to get on and off the device while in use, the device is able to accommodates many types of wheelchairs, easy to install, can fit current ADA required toilets, and design is compliant with current ADA requirements.

The ADA requirements are in place to make sure wheelchair users have enough space/room to move around and have access to the toilet in public spaces. The ADA has requirements for plumbing elements and setups in places like bathrooms to govern the minimum required dimensions and layout of toilet compartments. These minimums only deliver bare functionality and there are several problems with this type of layout.

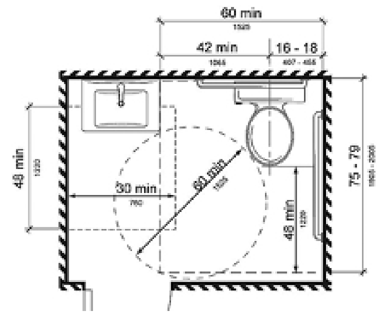

Figure 1: ADA dimension requirements for public restrooms [1]

Access to cleaning yourself is limited with this type of layout because the height of the toilet doesn't change and no supportive features are available for users. The transfer process in this setting is also challenging because the user has nothing to grab onto except the toilet seat, since the wall bar is too far away.

In previous years, other multidisciplinary senior design teams looked to meet these customer requirements by creating a toilet lift seat that is able to raise and lower to the height of a user's wheelchair to ease the transfer process for wheelchair uses. The device features support to help users with limited torso strength. The team felt this concept fit the given customer requirement and decided to continue moving forward with this design idea. Given this initial concept, the team came up with a detailed list of important engineering requirements that is able to test if the customer requirements are met by the designed device. The team considered all safety risks and possible device failure methods were determining engineering requirements. A few of the important engineering requirements included weight capacity for the device, no pressure or pinch points present, the device meets existing ADA requirements, and the device has an appropriate factor of safety for the structural components. Furthermore, an important customer requirement was the visual appearance of the device. Previous designs of the device had little visual appeal and were deemed "scary" by the customer. The team acknowledged the importance of visual appearance, so the team reached out to an industrial designer to bring onto the team and included engineering requirements to assess visual appearance of the device.

Description of Design

Engineering and customer requirements were collected through an interview with our client, Art North. These requirements, mentioned in the background section, were combined to create an overarching functional decomposition. The functional decomposition compiles the main functions required by the design. These included the ability to adjust seat height to the user, aid with sanitation, and provide both comfort and support to the user, all while fitting to existing toilet systems.

The main design focus was to use hydraulic cylinders that attach to a frame of the device that fits around a standard toilet system. The hydraulic cylinders then move the seat up and down through the use of hoses and a valve, allowing the user to adjust the seat height to match their needs.

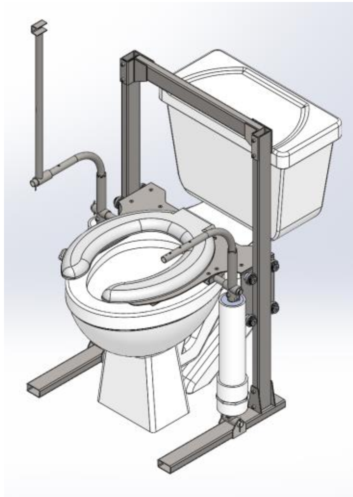

Figure 2: CAD rendering from P20011 design

Analysis of current products on the market lead to a variety of conclusions. Firstly, there were few products that would lift a toilet seat without including a tilt function. The team decided to go forward without a tilt function to provide the needed stability to users of the device. The market alternatives were compared both to each other and to the design produced by the previous team to develop ranges for key parameters including weight capacity, vertical distance, and price to the customer. A morphological chart was created with different design solutions compiled by team members. From there an overall design concept was decided upon. The features of the design were compared to the features of the design from last year in a Pugh chart. Original design ideas included an option for a bidet, but this was removed from later plans to simplify the design and make completion more feasible over a one-year time frame. Once the chart was completed, we discovered that the selected design was very similar to last year's design. Since last year's team lost out on manufacturing time due to COVID-19, the team decided that the logical design choice would be to utilize the design leftover, while making changes along the way as seen fit. Last year's CAD model is shown in Figure 2 above.

The team decided to use time during the Preliminary Detailed Design Phase to investigate last year's plans and pieces. CAD drawings were compared to the material left behind in the locker. It is at this point that the team ran into a large speed bump. The seat plate machined last year was nowhere to be found. The MSD floor was searched, as was the Machine Shop and the basement, but unfortunately the team realized that it must have been thrown away over the summer.

While we did make the decision to utilize the design from last year, there were a variety of changes to be made. The first change we made had to do with the mounting system. It had seemed that there was only enough material to adjust the mounts on the bottom and not the top. As such we decided to combine the mounting from the 2019 and 2020 designs. This combination would utilize the connections from the 2019 design; however, they would attach to the framing of the seat plate, which had been redesigned in 2020. One of the problems with the 2019 design was the almost medieval look it had, including the massive overhanging seat plate. The 2020 design featured a much slimmer seat plate that matched the shape of a generic toilet seat a lot better. The 2020 design used a steel plate as the base. Since our team would be utilizing almost all the leftover material, we could devote more of the budget towards the design seat plate. The team decided that using aluminum, while a bit more expensive, would lead to a much lighter overall product. The use of aluminum did mean that there could not be any welding done on the seat plate itself, but that would not actually lead to much of a change as welding something as thin as the plate would already lead to other problems, including warping.

The team spoke with Timothy Landschoot, a mechanical engineering professor in the College of Engineering, for guidance on the hydraulic system. He suggested running water through the hydraulics to observe baseline functionality. When the team did this testing, we discovered that the hydraulics get stuck when they reach the lowest position. The placement of the inlet/outlet hole on the bottom of the hydraulic cylinders was too low. When the top was filled with water, pushing the hydraulic down, the puck would go too far down, covering and effectively blocking the hole completely. This meant that as long as the current design was used, this system would only ever be able to go

down once and then would get stuck. We came to this conclusion after testing the hydraulics and seeing them get stuck in this position. We removed the fittings from the cylinder and could visibly see the piston blocking the hole.

For the above reason, the hydraulic piston required a redesign. The team decided to add a bit of length to the bottom of the rod. This length combined with the addition of a set screw to the piston cap would stop the piston from going too far down, covering the inlet/outlet hole. These design changes proved successful in keeping the hydraulics from getting stuck.

Previous designs included multiple connections of long tubing that only proved to complicate the design and make a mess. We decided to seek out a valve that would reduce the amount of hose required and simplify hose management. The valve needed to be a closed center, three position four-way valve. Such a valve would not run water through the system when not running by closing all of the internal connections. A closed center valve that was affordable could not be found, but an open center valve that included a plug to adapt it into a closed center valve was found and purchased. The three position four-way allows the valve to have one inlet, one outlet, and two connections to the hydraulics that change the flow pattern through the hydraulic cylinders. Fig. 3 shows the three settings for the valve.

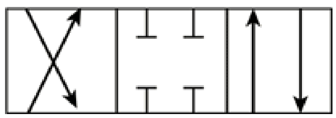

Figure 3. Flow Directions for a Closed Center 3 Position 4 Way Valve [2]

Once the hydraulics were situated the team moved on to arm design. We decided to utilize a puzzle piece connection that would allow for easy rotation both for support on the device and transfer. It was decided that the arms would be connected to the top of the hydraulic mounting with a weld. This is not the most ideal solution, and a stronger connection is recommended for the future. This connection is a compromise, and a product of the amount of time left in the semester as well as materials and a desire to get a complete working prototype completed before the last day of classes.

Figure 4. Complete CAD rendering for P21011 design

SUPPORTING FEASIBILITY EVIDENCE

The feasibility of several design aspects of the designed device were analyzed as described in the following section.

Functionality of the Hydraulics: The hydraulic actuation was modeled as a simple force balance between the water pressure within the cylinder acting on the area of the piston, which acts upwards against the maximum weight of 400 (lbs.). For the existing cylinders, a minimum water pressure of 30 (psi) is needed to operate the hydraulics, neglecting the deadzone and frictional damping effects of the o-rings, and the work needed to remove the water from the other half of the cylinder.

Usability: Pressure is the primary failure mode for the hydraulics. Modeling the hydraulics as a pressure vessel a pressure of 250 (psi) was calculated to induce cracking and subsequent failure in the main cylinders. Additionally, PVC pipes used for the cylinder body are rated up to 200 (psi) by the manufacturer, ensuring a factor of safety of two with respect to pressure. Similarly, the hoses and valve used are rated up to 2,000 (psi) and 10,000 (psi), respectively.

Corrosion: Steel will rust. Applying an anti-rust coating will make it resistant to rust. The interior of the hydraulic valve will tend to rust over time. However, the rusting of the valve is inevitable from the presence of dissolved oxygen in the water if it is not circulated for lengths of time. If the device is frequently used, this will not be an issue.

Durability: The device utilizes steel framing and armrests. Steel frame is strong enough to support the seat plate, A stress of 70,000 (psi) would be required to break any of the welds on the device, and the worst-case scenario is at the welds in the seat plate frame, but with a 400 (lb.) person, a stress of 2,000 (psi) is made on that point.

Arms: The durability of the arms is the primary concern as they are mimics of titanium arms found on the wheelchair of Art's son. A stress analysis indicates that a force of 500 (lbs.) would be needed to induce plastic deformation in the arms, giving a factor of safety of 2.5. Load testing of the arms did not show any permanent deformation.

Non-hazardous: All the materials are non-toxic towards humans according to standards. The materials selected are also able to be cleaned with everyday products.

Kinetic Stability: Using assumed static coefficient of 0.3 between steel and linoleum and assuming no load was on the device, a calculated force of 600(lbs.) was needed to tip over the device when applied left/right on the upper part of the frame, while a force of 800(lbs.) was needed to tip over the device from the back on the upper part of the frame.

MANUFACTURING PROCESS

Since last year's team did not produce manufacturing plans to build the prototype, the team started manufacturing parts from the materials that the team had available to us. The team had access to all materials needed to manufacture and assemble the frame so that was the team's first step. Majority of the pieces of the frame required welding to be done, which led the team to bring in Cam as a welding expert to complete the needed welding tasks. With the welding assistance, the team machined and manufactured the frames 'feet' and the hydraulic system mounting bases (Fig. 5a and Fig. 5b).

(a) (b) (c)

Figure 5. (a) Image of Welded Frames 'Feet' or base of device (b) caps for the bottom ends of the hydraulic cylinders with the mounting system (c) the hydraulic cylinders mounted as designed to the base of the frame.

Once other aspects of the frame from last year started being assembled, the team noticed that some parts were not machined to their listed specs based on their drawings. For example, for the hydraulic system mounting base, the rod was supposed to fit through the two plates on either end as on the base of the frame seen in Fig. 5c. However, since the machined parts had some tolerance associated with them, the interference was too great to allow the rod to slide through. To remedy these problems, the team widened all the previously drilled holes to account for the different tolerances on the parts. In the case of the hydraulic system mount, the rod was shortened and welded to inside the plates on the frame as seen in Fig. 6a below. Other issues came up during the manufacturing process. When the team began to weld together the main frame of the device, the crossbar from the previous iteration that was welded to the frame is two inches short of the designed length. This would prevent the seat plate from fitting properly inside the frame. The team's solution to this was to cut the crossbar in the middle and weld additional box tubing and additional

inside structural supports to make the frame wider, which got around having to remove welds and potentially damaging the materials. The finished frame is shown in Fig. 6b. Another issue that the team noticed with last year's design was that previously manufactured support parts for the main frame were not bent correctly. The incorrect bend placements prevented the supports from aligning with the frame and were impossible to weld as designed (Fig. 6c). The frame is sturdy without these additional supports, so the team decided to leave these parts off, and we will re-machine the supports if needed based on the results of the testing.

(a) (b) (c)

Figure 6. (a) redesigned hydraulic cylinder mount (b) completely welded frame (c) incorrectly machined supports for crossbar

The next aspect of the design that was manufactured was the seat plate and framing under the seat that supports the users during use of the device. The seat plate was machined with the plasma cutter, based on last year's drawings. Then the framing for under the seat was welded together (Fig. 7a). The image of the seat plate and frame together is shown in Fig. 7b.

(a) (b)

Figure 7. (a) frame for under seat plate (b) seat plate and framing structure

To get the bearing guides in place, the bearing guide attachment fixture needed to be welded to the seat plate frame (Fig. 8a). Once that was complete, the bearing guides, with the bearing guide spacers, were assembled onto the frame (Fig. 8b). After assembling the bearing guides, the team noticed that the bearings do not properly align with the frame of the device. This is due to the holes drilled on the bearing guides, being cutout on the waterjet by last year's teams. The tolerances of the waterjet were not properly considered. This gap causes the seat plate to tilt forward when weight is applied. To fix this the team added a rubber spaced against the frame to prevent this movement of the bearing guides. To attach the hydraulics to the frame, bars were welded to the seat plate frame as seen in Fig. 8c, and then the mounting brackets from the 2019 team were used.

(a) (b) (c)

Figure 8. (a) bearing guide attachment fixture (b) assembled bearing guides on frame (c) bars welded to frame to attach seat plates

While the manufacturing process with the frame was occurring, the redesigning, machining, and assembling of the hydraulic pistons was happening simultaneously. As stated previously, after testing the hydraulics, the team learned that the hydraulics were nonfunctional due to the hydraulic piston rods being too short. This causes the hydraulic piston to block the inlet/outlet and cause the hydraulic to be stuck in the down position. To solve this problem, the team re-machined the piston rods and extended the portion that extends through the piston. Additionally, a set screw was added into the brass end plug for adjustable spacing. After these adjustments, individual testing of each cylinder was successful, each could move between upper and lower positions without getting stuck. Moreover, for the hydraulic system a 4-way, 3 position hydraulic valve was purchased. The valve was placed onto the seat plate and positioned, and holes were drilled into the plate to fix the valve to the device.

The final machined aspect of the device was the arms. To machine the arms, the staff in the machined shop machined the grooves in the shaft for the arms. Eight grooves were machined to allow for the arms to be positioned into 8 different positions. The arms were then bent to the desired angle. The shaft was welded to the frame and the arms and the locking part for the shift were attached together. The machined shafts for the arms are shown in Fig. 9.

Figure 9. the machined shafts for the arms with the 8 positioning grooves

BUDGET

The Bill of Materials details all the part components intended to put our device/prototype together. The Bill of Materials document keeps track and makes sure all expenses can be afforded with our $500 budget. Given most of the material from last year was reusable and was in our locket already, we did not need to request a budget increase. The material left in our locker from last year's team had a value of $351.63. Our group focused on determining what we had and what we still need based on the last year's design. We realized we needed to order and design a new seat plant along with a ceramic covering or paint. The Bill of Materials document was updated accordingly each phase. Some of our larger purchases were the seat plate material and the Monoblock Hydraulic Valve. So far, we have spent $359.11 which is well within our budget. If more time was allowed, our remaining budget would be used to touch up the design to make it more aesthetically pleasing for the user.

RESULTS, CONCLUSION, AND RECOMMENDATIONS

The major success of this project is the completion of the device prototype. Despite the machining and material setbacks experienced throughout the year, the team refined the previous iterations design into a functional device. The CHAD device has met or exceeded the majority of our engineering and customer requirements including operating within an optimal PSI range, exceeding minimum height requirements to ensure it fits over the majority of toilets, and providing sufficient support to the user. We worked together to test the device and brainstorm solutions

when problems occurred (which was often). A big factor in this team's success was acknowledging when the information we had was insufficient or when a design idea was no longer feasible. We were able to quickly adjust the design and manufacture what was needed to build a successful prototype. The arm design adjustments due to CAD deficiencies and the spacer material sourced from the MSD surplus used to fix our seat plate/bearing motion issues are a great example of the problems that arose during the year and the work our team put into resolving them. The image of the final prototype is shown in Fig. 10.

Figure 10. Final Assembled Prototype

The hydraulics system, while functioning, is too small for the current state of the device and is not capable of meeting the weight capacity of 400lbs. Future teams assigned to this project should be tasked with building a larger system that can still function within the required PSI range. In this iteration comfort was considered an important factor but did not take priority over the completion of the device. During further work on this project, team members should consider human subject testing to receive feedback on overall comfort, ease of use, and design appeal. This information will be crucial in developing a final prototype that could potentially be ready to be marketed. This team suggests utilizing the skills of an industrial design student in order to best meet the needs of the client and eventually the potential users.

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