UNIVERSITY OF MANITOBA

MECH 4860 – ENGINEERING DESIGN

Final Design Report

A Process Improvement for the Removal of Steel Cores from Slitting Machines for Winpak Ltd.

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Executive Summary

Winpak produces packaging equipment used in food packaging industries. One of Winpak's main procedures is reducing larger wide rolls of packaging material into three equally narrower rolls of material. This process is done using a slitting machine. Steel cores are used to load the material on the slitting machines. The steel cores have the material wrapped around them and are connected to the slitting machine by way of the chucks. There is a tight fit between the chucks and the steel cores, and about 50% of the time the cores get stuck on the chucks. The current removal procedure involves a pry bar and a steel tube. The process begins by using the pry bar to create a gap between the chuck shoulder and the steel core. This part of the core removal process is the most difficult. The process then involves using pry bar to continue sliding the core off the chuck. Eventually, the steel tube is needed to create leverage. The steel tube is inserted between the chuck shoulder and the pry bar to bring the pivot point closer to the end of the core. This part of the process allows the operator to slide the core off the chuck with the pry bar. This current process is a safety hazard for employees and damages the steel cores and chucks. Our team's objective is to design a solution that safely and efficiently removes the steel core without causing damage.

Our final design solution is an improvement to the current process. The current core removal process takes 3-30 minutes depending on how severely stuck the core gets. With the modification, the process time has been decreased to 3-5 minutes. The design involves machining a slot in the shoulder of the chuck the size of the pry bar tip. This modification creates the initial gap that is so hard to create. The slot makes the process safer by giving the pry bar a more secure grip between the chuck shoulder and the core. We have also added a grip to the pry bar where the operator holds the pry bar. This gives the operator a secure grip on the pry bar, preventing his hand from slipping. The final modification made is a coating applied to the end of the pry bar. This prevents the steel on steel contact that was causing damage to the cores and chucks. However, simplicity was very important for the operators, and this solution provides that. One of the chucks was also modified and tested. To this point, the operators have been very happy with the results. The modifications work well and Winpak plans to implement for all the chucks.

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1. Introduction

Winpak is a company located in Winnipeg that produces and distributes plastic packaging films. The company has contracted our team to design a procedure to remove steel cores from Winpak's slitting machines. Due to high demand for plastic sheets, there is need for efficient machinery and automation. Winpak works at full capacity and yet cannot fulfill the demand. Therefore, there is a need to speed up some of the tasks so as to increase productivity, as well as provide a safer working environment for the operators that reduces injuries to the operators.

This report presents the background of the company and its current process of core removal, a project description that includes the problem to be solved, project scope, objectives, requirements, deliverables, constraints and risks. The final design is thereafter described in detail, including how the design meets the client needs. This report also presents the cost analysis for the final design. Attached to this report are appendices that include the other concepts that were considered in the concept definition phase of the project. The appendices also include the project management tools that we used to keep track of this project.

1.1 Company Background

Winpak was established in 1977, and it produces and sells packaging materials. The company also does research and development on packaging machines. Most of the company's plastic is used to wrap food and beverages [1]. For the past two to three years, the company has been running at 100% capacity, as we were told by Chris Sheppard, the Process and Project Lead, during our site visit. Due to the high demand for the packaging film, Winpak realized that there was a need to optimize the current processes. Winpak sees an opportunity to reduce the overall process time by devising an efficient core removal process and at the same time, providing safety to operators.

1.2 Process Background

The process that this project focused on involves slitting machines. Slitting machines convert large rolls of material into narrower sections of material [2]. Winpak has six Multi Barrier slitting machines in which the steel cores are used. The steel core is mounted onto the chuck of the slitting machine as shown in Figure 1. The current Multi Barrier (MB) slitting machines have steel cores which are approximately 2.8 meters wide with an 8-inch outer diameter, and weigh 110 kilograms. However, Winpak has ordered new slitting machines on which a 4 meter wide steel core will be used. The steel core is mounted onto the chucks that are connected to a rotor, which rotates the steel core to unwind the packaging material that has been wound on the core.

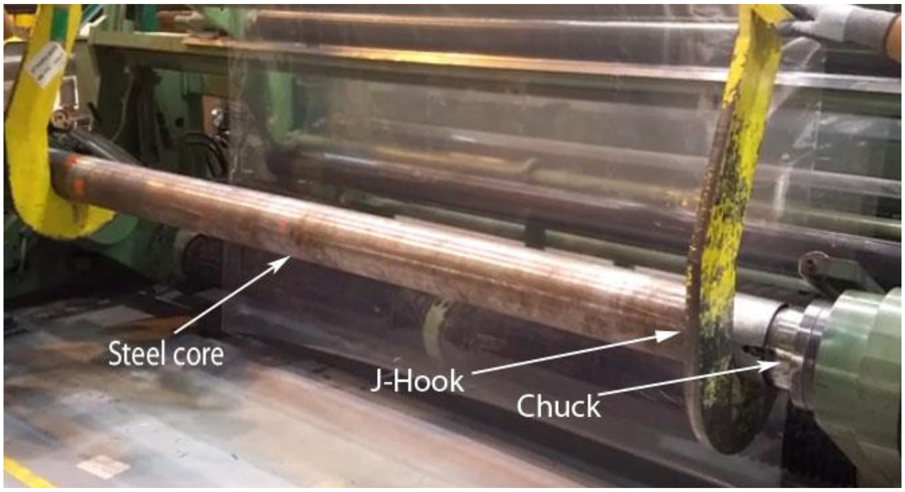


Figure 1: Slitting machine showing the steel core mounted onto the chucks. The chuck on one of the sides is fixed while the other one is free to move outward, along the axis of the core, to allow the removal of the core [3].

When the material is unwound, the wide stock of material is cut into smaller rolls that are narrower than the initial stock. Once the material on the core runs out, it needs to be replaced by a new core that is loaded with the plastic material. The flowchart shown in Figure 2 shows the steps that are currently followed to replace the core of the slitting machine. To remove the steel cores, Winpak uses a crane with two J-hook attachments that lift the core. When the core is still on the chucks the J-hooks are put in place. Then the arms of the slitting machine open up by moving laterally and pull the chucks out of the steel cores. The core is then free and the operator can lift and move the cores with the crane. The cores are placed on carts so that they can be taken to get more material. This is a very simple process except when the steel core gets stuck on the chuck.

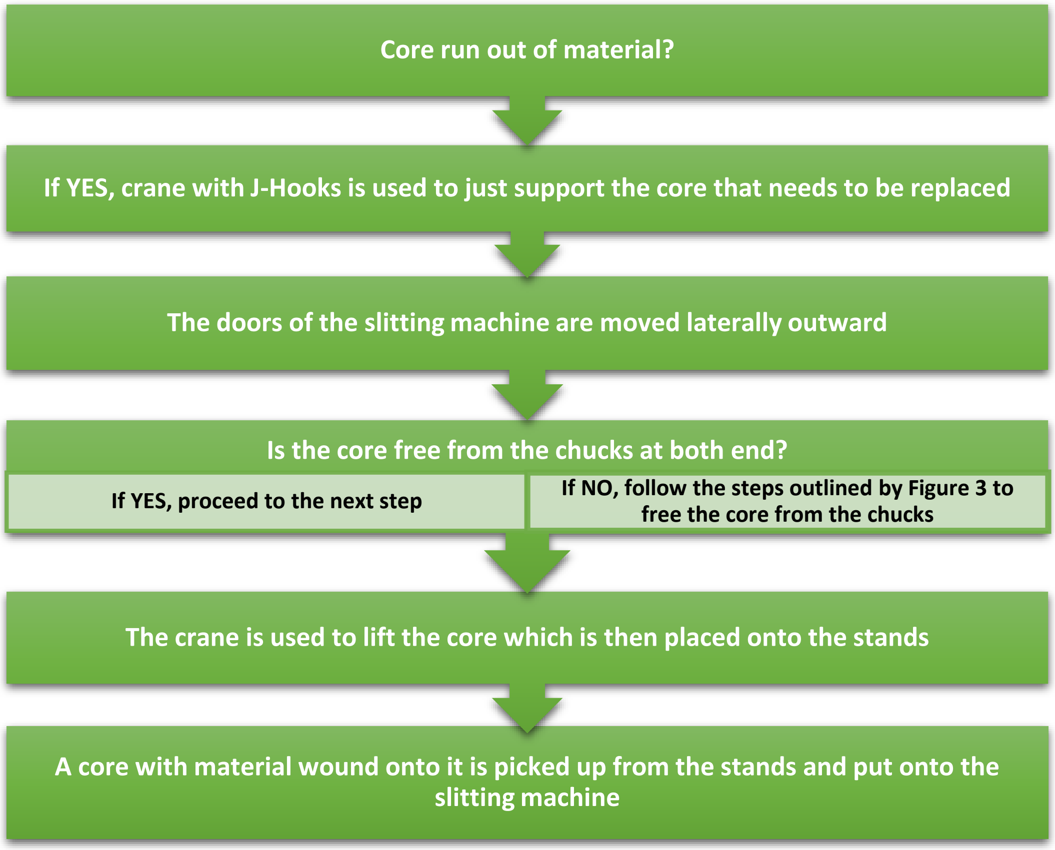
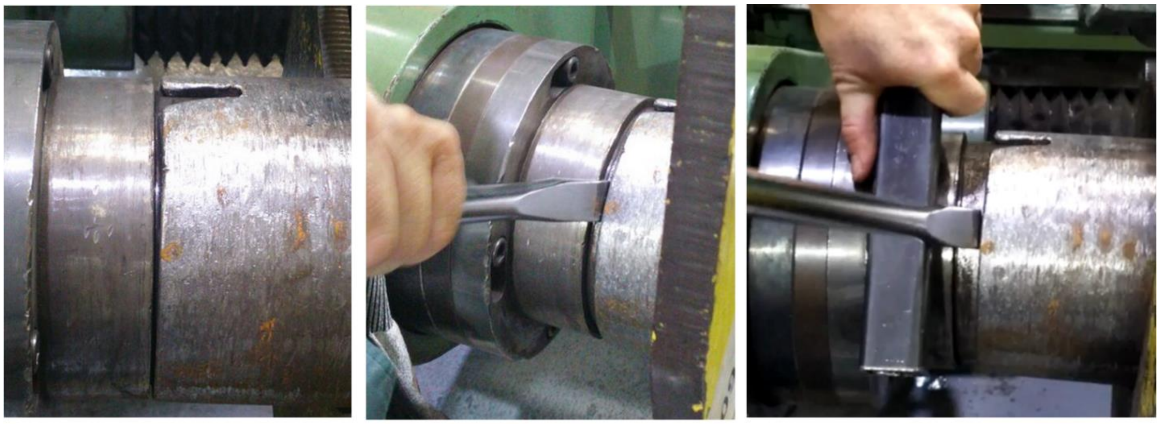


Figure 2: A flowchart showing the steps that operators at Winpak currently follows when removing the core from the slitting machine.

The cores get stuck onto the chucks about 50% of the time according to one of the operators. The core gets jammed on the chucks of the slitter due to the tight fit between the core and the chuck. One of the leading causes for the tight tolerances is deformation to the cores after a prolonged period of usage. This makes it difficult for the operators to take the core off the chuck, as seen in Figure 3. As a result, an excessive amount of force is required to take the core off. The operators currently use a metal tube and a pry bar to remove the core. Stage 1 in Figure 3 shows the tight fit between the core and the chuck. Stage 2 shows the gap created by the use of a pry bar. This is the most challenging task. Finally, stage 3 shows how the hollow tube is used in conjunction with the pry bar.



Stage 1 Stage 2 Stage 3

Figure 3: The current process of removing the core from the chuck, which can be divided into three main stages: 1, 2 and 3. Initially, there is a tight fit between the core and the chuck. A pry bar then needs to be used to create a space between the two components and then finally sliding out the core from the chucks to remove it [4].

This current removal process poses a number of problems. There are health and safety risks to the operators since the pry bar might slip out of the hand and injure the operator. Typical injuries during this process include pinches and cuts on the hand, and stress on the back. This process also damages the core and chuck. When trying to create the initial gap, the pry bar is used in a way that damages the ends of the cores.

In the past, Winpak has used various types of oils to lubricate the chuck and the core, reducing the friction between the two. However, over a period of time, the oils create an accumulation of dirt in the interior of the steel core, adding the need for periodic cleaning of the cores and the chuck, which was found to be costly since Winpak would need to hire staff to clean the cores.

1.3 Project Description

With a full understanding of Winpak's problem, the parameters of the project were set. This section outlines these parameters through the problem statement, project purpose, scope, customer requirements, target specifications, deliverables, acceptance criteria, constraints and high-level risks.

1.3.1 Problem Statement

Winpak's slitting machine core gets stuck 50% of the time, which leads to delays in the overall process, since the steel cores need to be reloaded onto the machine 7-8 times in an 8-hour shift. The current process used to remove stuck cores also poses a serious safety concern to the employees. The most common injuries the operators suffer are the pinches and cuts on hands caused by using the pry bar. However, no specific data of injury frequency is available, but it is significant. In addition, the current process also damages the components of the slitting machine.

1.3.2 Project Purpose

The goal for this project is to develop or improve the core removal process which will allow the operators to safely and efficiently remove the steel core from the chucks without causing damage to the cores or chucks. The new idea either needs to reduce the frequency of the jam or be able to deal with the jam within 3-5 minutes.

1.3.3 Project Scope

The scope of this project includes the following:

- Developing conceptual designs for the core removal
- Selecting the final solution
- Documenting the final solution in a way that client can implement it
- Performing cost-benefit analysis
- Conducting trial tests to confirm effectiveness of the design solution*
- Conducting Finite Element Analysis (FEA)*

*This was not included in the original scope, but due to the change in schedule our team had enough time to conduct tests to determine the feasibility of our final design.

1.3.4 Project Deliverables and Acceptance Criteria

The deliverables for this project will be measured by the acceptance criteria noted below to ensure that the project objectives are met. The following are the deliverables that need to be met by the project deadline:

- Final Design Report
- Project Poster
- Design Procedure
- Design Description and Drawings

The acceptance criteria for all of the aforementioned deliverables were approvals from the client.

1.3.5 Customer Requirements

After our first meeting with the client, a list of customer requirements was developed, which is as follows:

- Portability
- Safety
- Ease of use
- Efficiency
- Ease of handling
- Cost effectiveness
- Durability
- Effectiveness
- Minimal manual input force
- Weight

More details of some of the customer requirements are discussed below to better understand the client's needs.

Ease of use: The current process being used to remove the steel cores is a very simple. Therefore, it is important that our design is not complicated. If the solution we design is complicated the operators will forgo it for a simpler option.

Lightweight: Our team's design must be lightweight to ensure that extra weight does not increase the chance of operators getting injured.

Cost: The material for the current system is stainless steel, which is not expensive and is sold commercially. The cost of our design needs to be less than or the same as the current system.

Safety: Winpak has to comply with work safety codes at minimum. Although the current system is efficient and effective, it lacks the required safety. With the current system, an operator can sustain an arm injury. Figure 4 shows the how the pry bar and the metal tube are being used in the current core removal process. The pry bar can easily slip, thus injuring an operator's arm. Furthermore, the design needs to be food grade certified according to health and safety standards [1].

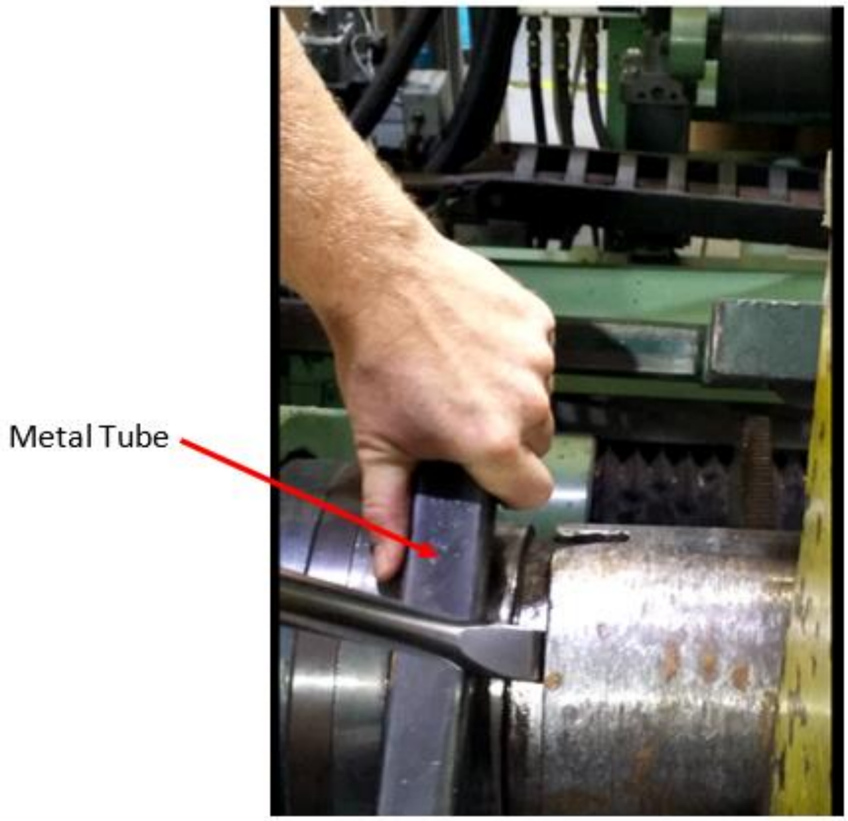


Figure 4: An operator holding the metal tube with his hands close to the rotating areas of the slitting machine can be unsafe [5].

1.3.6 Target Specifications

With the customer requirements set, a list of target specifications was developed. TABLE I shows the list of target specifications, the metric for each of the specifications and its priority. Our team weighed each specification with the purpose of prioritizing them to set achievable goals. The resulting priority that was assigned to each objective was based on a consensus from the team and information from our meeting with the client. The priority is from 1 (least important) to 4 (most important).

TABLE I: PRIORITIZED TARGET SPECIFICATIONS AND METRICS BASED ON CLIENT'S NEED

Target Specifications	Metrics	Priority
Cost of design materials	<$1000	2
Number of ways to transport	>1	4
Weight of the design	<22kg	4
Manufacturing cost	<$1000	2
Force required by operator	<200N	4
Time it takes to remove core	<5 minutes	4
Size of design	<85"X216"	4
Life cycle	>2000 uses	3
Training requirement	<5 minutes	4
Probability of success	100%	4
Safety	Number of ways to cause damage and injury	4

The highest-ranking specifications were based on the client's need for the design to be efficient, effective and safe.

1.3.7 Constraints and Limitations

Constraints and limitations had a direct impact on the design that our team came up with. Therefore, it was key to strictly define the constraints.

- No major change to the core or the chuck are allowed

  There are more than 200 steel cores used for winding and rolling packaging film process. Therefore, making changes to the cores was not feasible. Making changes to the chuck would be reviewed by the client. However, the client advised that making changes to the chuck would compromise the strength of the chucks. A pair of chucks costs just over $3200 and therefore manufacturing new chucks was also not feasible.
- Budget of $2000

  Winpak provided our team with a budget of $2000. The solution that our team came up with had to be within this pre-assigned budget.
- Project schedule

  The course gave our team a final deadline for the design. This date was December 7, 2015. Going beyond this date was not an option, but working ahead and staying on top of tasks allowed us to complete the project within the schedule.

- The number of people available to use the designed solution
  The task of removing the steel core from the chucks involves two operators. Occasionally, there is a third operator that helps, but in general our solution will have to involve two or fewer operators.
- Limited open space around the machines
  The solution that is designed must be easily and safely operated within the available space. Figure 5 shows the space that is available in front of the slitting machine.

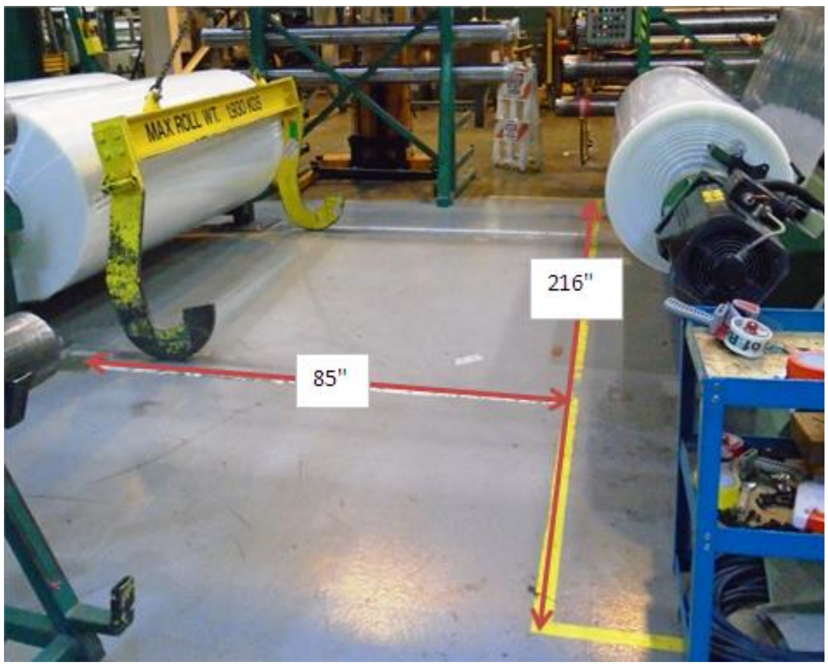


Figure 5: Dimensions of the work area in front of the slitting machine [6].

1.3.8 High Level Risks

In this project, there were potential risks that could have affected the project schedule. The risks are listed below:

- The risk with human resources.
  It may occur that one of the team members could fall ill and not be able to do his or her part of the project.
- The risk in availability of computer resources.
  Particularly for software such as Dropbox, SolidWorks. For example, our team is using Dropbox to share documents. Maintenance or failure of Dropbox will cause delays in the project schedule.
- The risk of the group members dropping out of the course.
  This would significantly affect the project in a negative way.

However, our team avoided these risk by thinking of a counter-plan to avoid each of these risks. Our team set internal deadlines for deliverables in advance of the deadlines set by the course. This extra time gave our team the flexibility to address the effects of the risks. For more information on the project management tools that our team had used can be seen in Appendix C of this report. Our team had in place a schedule that we kept us on track to finish this project by December 7, 2015.

2. Final Design

The flow chart in Figure 6 shows the process that was followed to come up with the solution to the problem. The project was split into three major phases. The three phases were problem definition, concept design and final design.

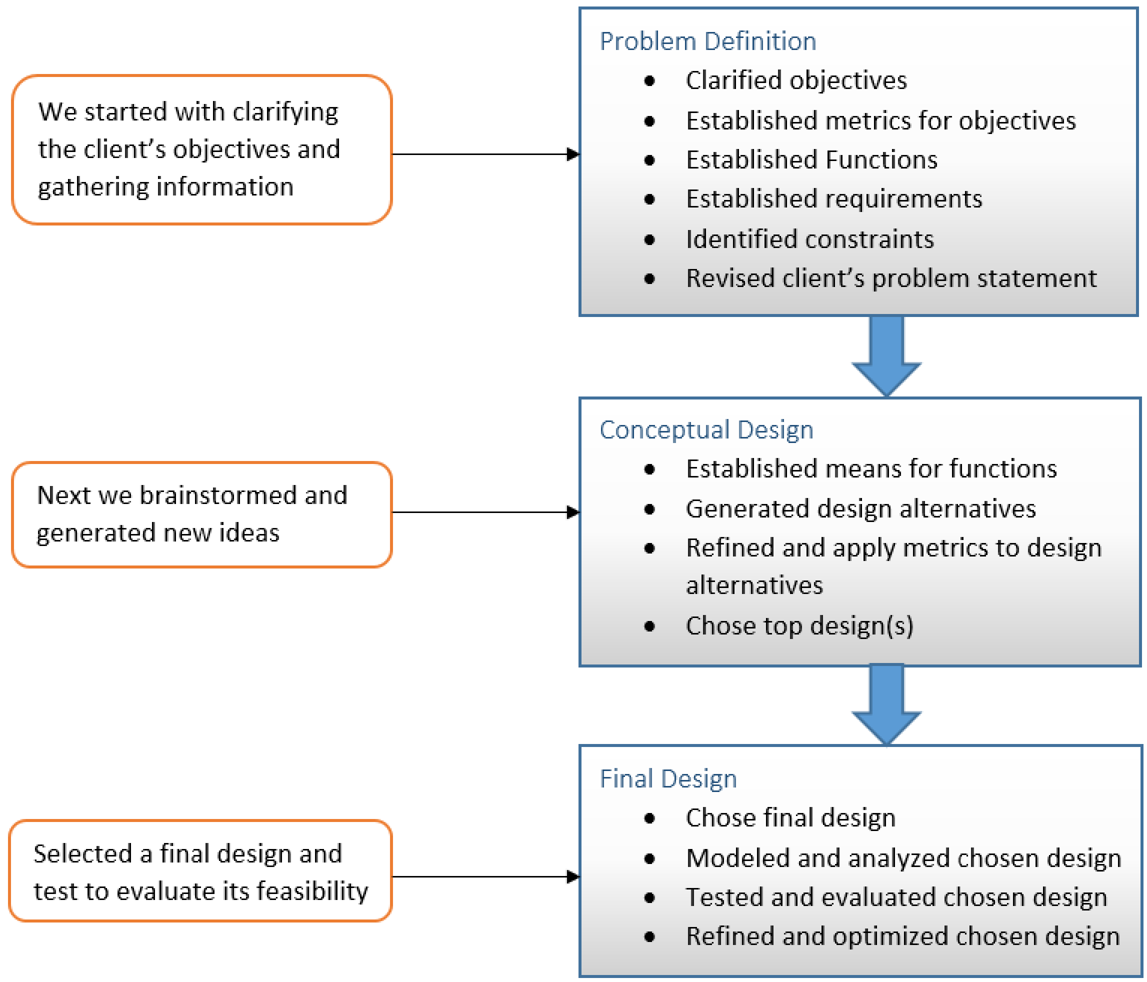


Figure 6: Flowchart of design process.

Six concepts were generated and concept screening was performed. This process was used to select the best concept. More details on the concept generation and concept screening can be found in Appendix A and B, respectively.

2.1 Components of the Design

The following is a description of the different components of the final design and their functions. The main features of the final design include the modified chuck and the pry bar.

2.1.1 Chuck

A slot was cut into the shoulder of the chuck, as seen in Figure 7. The dimensions of the slot in the chuck are 1” by ¼” by ⅜”. These dimensions were chosen based on the size of the sharp tip of the pry bar. The slot was designed to be slightly bigger than the sharp end of the pry bar to provide clearance. It is proved later in the report with FEA that the slot did not affect the mechanical properties of the chuck since it was relatively small as compared to the chuck. This slot can be manufactured on a CNC milling machine, according to the detailed drawings in the Appendix D. The slot created a space between the chuck shoulder and the steel core, as seen in Figure 8, and the slot was wide enough to just fit the flat end of the pry bar. The close fit between the slot and the pry bar was meant to prevent slippage and provide support when prying the steel core off the chuck. Furthermore, the slot provided that initial space for the pry bar because in the current process, the operator had to wiggle the steel core back and forth, several times to create that space.

Figure 7: Before and after pictures of the modified chuck with the new cut-out slot [7].

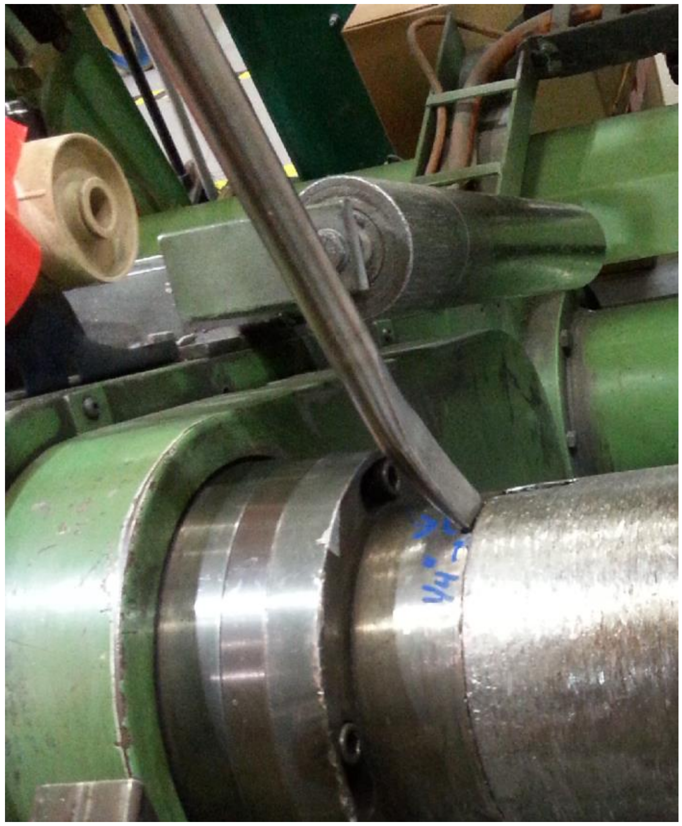


Figure 8: The pry bar fits into the slot that is cut out from the chuck [8].

2.1.2 Pry Bar

The design of the proposed pry bar is the same style as the current one. Because the metal pry bar will be in contact with the chuck and the steel core, rubber coating was added to both ends of the pry bar to prevent wear and tear from metal on metal abrasion as shown in Figure 9. The rubber coating on both ends of the pry bar also provided frictional resistance between the pry bar and both the chuck and the steel core. Furthermore, a rubber grip has been added to provide additional support for the operator handling the pry bar as well as to prevent the pry bar from slipping out of the operator's hand.

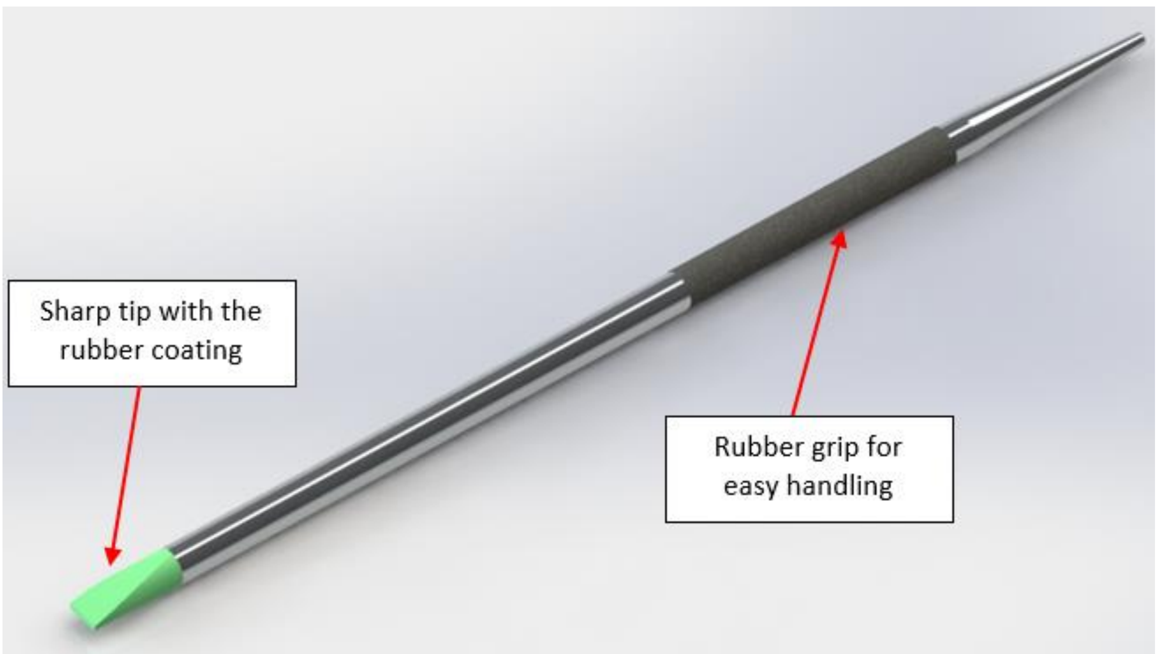


Figure 9: Pry bar with rubber coatings on both ends and a rubber grip

The dimension of the pry bar is given as 24'' in length and ¾'' in diameter [9]. Therefore, the handgrip should have an inner diameter about ¾'' to maintain the tight contact between handgrip and pry bar and have a length of 6''. The handgrip can be placed at approximate location of quarter length close to the tip.

Special rubber coating can be applied on the sharp end of the pry par to decease the abrasion between the sharp tip and the notch on the shoulder of the chuck. The wear and abrasive coatings can be used to meet the requirement of being durable. There is a multi- purpose rubber coating from Plasti-Dip that can be used to protect the metal surface from being scratching easily [10].

2.2 New Design vs. Customer Requirements

Some of the customer requirements for the design were efficiency, safety, cost, portability, lightweight and durability. Described below is how the new design meets the customer requirements:

Efficiency: The current process was not effective at instances when there was a tight fit between core and chuck. As seen in Figure 3 and described in Section 1.2, the most time consuming step in the tight-fit situation is the initial stage in which the flat pointed end of the pry bar is used to create a small gap between the shoulder of the chuck and the core. The challenge is to get the pry bar into the contact area between the core and the chuck. Cutting out a notch has solved the main part of the problem. The notch gives the initial space to pry off the core from the chuck.

Safety: The existing pry bar design posed risks of injury to the operator since the pry bar did not have enough grip. Therefore, the operator's hand might slip off of the pry bar and hit the surrounding space. This lead to cuts and pinches on the operator's hands. Adding a rubber grip can give the operator more grip and this will reduce the chance of the pry bar from slipping off the hand.

Cost: A $2000 budget was assigned to this project. The new design cost is well below the budget. In a meeting, the client mentioned that the cost the new design can be considered negligible compared to the cost of the chuck. Details cost analysis is included in Section 2.6.

Portability: Our new design is just as portable as the old design therefore it can be assumed to be portable and meets the client need.

Lightweight: The same pry bar will be used for the new design. An additional grip is to be added to give the operator more grip. The weight of a rubber grip is relatively small and will have no significant effect on weight of the pry bar to go beyond 20 kg, which is the upper limit of the allowed design mass.

Durability: The problem that the original design faced was that the core removal process caused damage to the shoulder of the chuck and the pry bar. Figure 10 shows how the pry bar causes damage to the shoulder of the chuck when prying the core off the chuck. The white circle marks the point of contact between the shoulder and the pry bar. When the shoulder of the chuck is worn out badly, the chuck is sent out for shoulder rebuilding but the integrity of the chuck can be changed. In addition, the pry bar also wears out at the location that comes into contact with the shoulder. This wear to the shoulder and the pry bar can be eliminated by adding a rubber coating to the shoulder of the chuck and the sharp tip of the pry bar. This makes our design more durable than the current design.

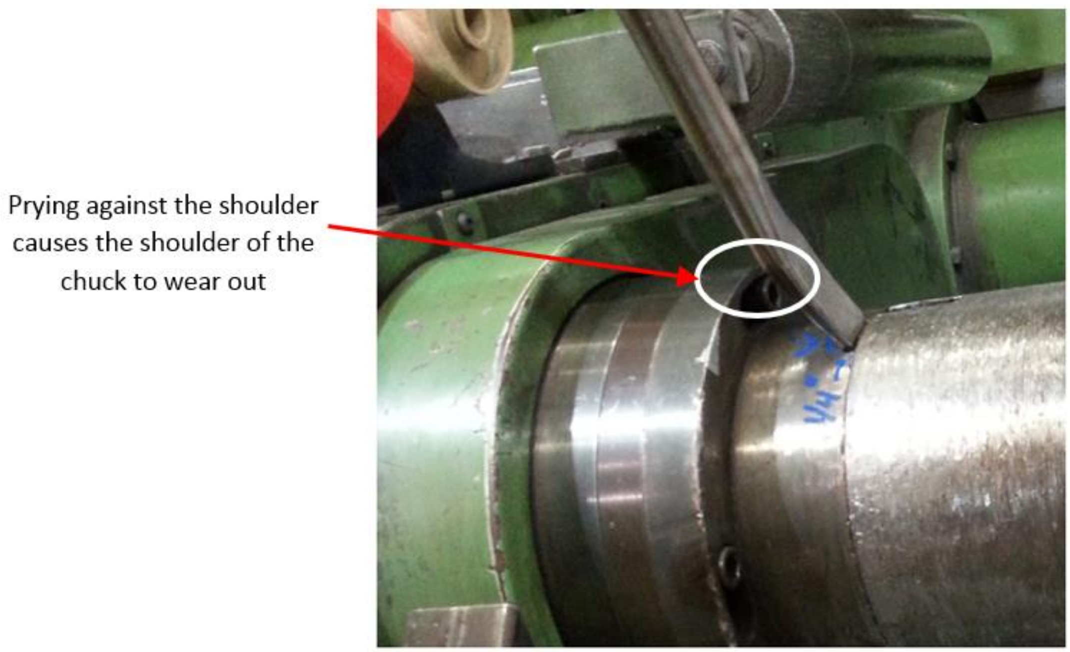


Figure 10: Prying against the shoulder causes dents on the shoulder and also wears out the pry bar [11].

2.3 Finite Element Analysis (FEA)

FEA was performed in order to prove that the modifications to the chuck do not affect its integrity. SolidWorks was used to perform the FEA. The client was not able to quantify the loads applied to the chuck. For the purposes of this analysis, arbitrary loads were applied to the previous chuck and the modified chuck to make a comparison. A torque of 50 Nm was applied to the surface of the chuck that is in contact with the core. A downward vertical load of 50 N was also applied. The results of this analysis are shown in Figure 11.

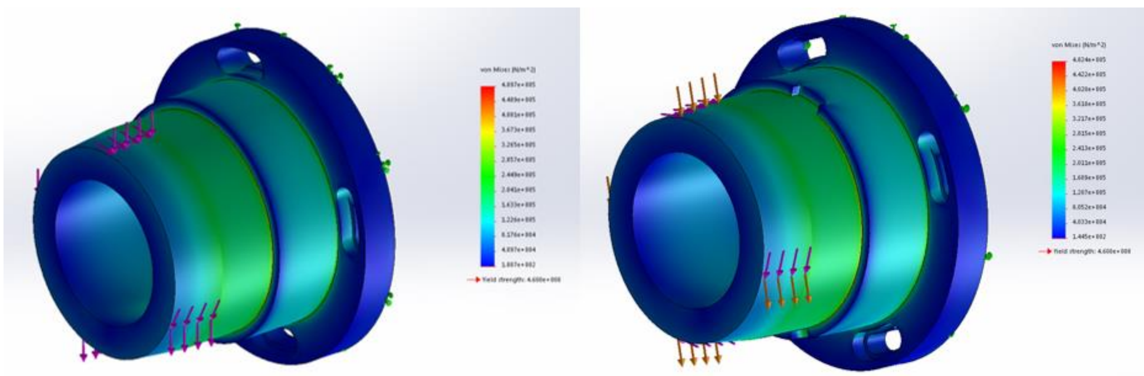


Figure 11: On the left is the vonMises stress contours for the original chuck and on the right is the vonMises stress contours for the modified chuck

As can be seen in Figure 11, the modifications to the chuck make a negligible change in the stresses on the chuck. This proves that the modifications that we have made to the chuck will not affect its strength. More information on the FEA process used is shown in Appendix D.

2.4 Testing the Final Design

In the project scope we stated that testing would not be done for this project. However, due to the changes in our timeline, we had adequate time to do some testing. Our team came up with the solution of machining the chuck early in the process, which left enough time for Winpak to send out one of the spare chucks to get the slot machined.

When Winpak got the chuck back after being machined, the operators installed it on one of the slitting machines. Our team was present when they first put it in to use, but unfortunately none of the cores got stuck while we were there. Our contact (Chris) at Winpak said he would see how the next couple days went with it in use and also obtain feedbacks from the operators about its performance. Over these days the cores did get stuck and our solution was put into action. The feedback that Chris got back from the operators was positive. The slot allowed the operators to initially get a better grip on the core. They did not have to struggle to create the initial gap between the chuck shoulder and the core. To this point we have heard only positive reviews about the solution, so we are confident in the solutions effectiveness. Winpak plans to continue ramping up the testing by machining another chuck. If it continues to perform as it has so far, they plan to have all the chucks modified in this way in the near future. However, there are no testing done on the modifications to the pry bar as of the end of this project. This testing will be left to Winpak as to how they want to implement that.

2.5 Failure Mode and Effect Analysis

In order to identify ways that the core removal process can fail and mitigate the risk for our final design, we decided to apply Failure Modes and Effects Analysis (FMEA) to explore the potential failure mode and give recommended solutions on our design. Here is a list of some detailed steps involved in FMEA Process [12]:

- Define the requirements.
- Construct a Block Diagram.
- Identify key components, functions and interfaces.
- Construct a Cause and Effect Matrix to prioritize relationships.
- Identify critical parameters and the potential failure mode for the process.
- Identify the potential effect of each failure mode and the severity.
- Identify the potential causes of each failure and the probability of occurrence.
- Identify the current controls and the ability to detect a failure mode.
- Determine the Criticality.
- Calculate the Risk Priority Number (RPN) for each failure mode.
- Determine Risk Priority for Action.

Before we analyzed the potential failure modes by following the steps listed in FMEA process above, we were required to define the detailed rating scales for severity, probability and detectability first so that we could distinguish the differences between each potential failure mode by assigned different values from the perspectives of the severity of the potential failure modes, their probability of occurrence and the ability of detecting them. Detailed rating scales are shown in TABLES II, III and IV respectively.

TABLE II: SEVERITY RATING SCALE [13]

Effect	Severity of Effect	Ranking
Hazardous without warning	Very high severity ranking when a potential failure mode affects safe system operation without warning	**10**
Hazardous with warning	Very high severity ranking when a potential failure mode affects safe system operation with warning	**9**
Very High	System inoperable with destructive failure without compromising safety	**8**
High	System inoperable with equipment damage	**7**
Moderate	System inoperable with minor damage	**6**
Low	System inoperable without damage	**5**
Very Low	System operable with significant degradation of performance	**4**
Minor	System operable with some degradation of performance	**3**
Very Minor	System operable with minimal interference	**2**
None	No effect	**1**

TABLE III: FREQUENCY RATING SCALE [13]

Probability of Failure	Failure Probability	Ranking
Very High: Failure is almost inevitable	>1 in 2	**10**
	1 in 3	**9**
High: Repeated failures	1 in 8	**8**
	1 in 20	**7**
Moderate: Occasional failures	1 in 80	**6**
	1 in 400	**5**
	1 in 2,000	**4**
Low: Relatively few failures	1 in 15,000	**3**
	1 in 150,000	**2**
Remote: Failure is unlikely	<1 in 1,500,000	**1**

TABLE IV: DETECTION RATING SCALE [13]

Detection	Likelihood of Detection by Design Control	Ranking
Absolute Uncertainty	Design control **cannot** detect potential cause/mechanism and subsequent failure mode	**10**
Very Remote	**Very remote** chance the design control will detect potential cause/mechanism and subsequent failure mode	**9**
Remote	**Remote** chance the design control will detect potential cause/mechanism and subsequent failure mode	**8**
Very Low	**Very low** chance the design control will detect potential cause/mechanism and subsequent failure mode	**7**
Low	**Low** chance the design control will detect potential cause/mechanism and subsequent failure mode	**6**
Moderate	**Moderate** chance the design control will detect potential cause/mechanism and subsequent failure mode	**5**
Moderately High	**Moderately High** chance the design control will detect potential cause/mechanism and subsequent failure mode	**4**
High	**High** chance the design control will detect potential cause/mechanism and subsequent failure mode	**3**
Very High	**Very high** chance the design control will detect potential cause/mechanism and subsequent failure mode	**2**
Almost Certain	Design control **will** detect potential cause/mechanism and subsequent failure mode	**1**

Finally we conducted FMEA analysis for our design and summarized our FMEA results in TABLE V, where **Risk Priority Number** (RPN) was calculated as the product of the values of severity, probability and detectability.

TABLE V: FMEA SUMMARY

System	Steel Core Removal Process	**Potential Failure Mode and Effects Analysis**	**FMEA Number** MECH 4860 Eng. Design
Design Team	Team 25	**(Design FMEA)**	**Prepared By** Jia Zhe Liu
			FMEA Date 11/27/2015
		Date 11/27/2015	

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)**
Core removal during roll change	Abrasion on the chuck shoulder.	May cause damage to cores and/or chucks.	6	Both pry bar and chuck are made of stainless steel, removal process occurs at a high frequency.	2	Add rubber protection around chuck shoulder, where is used as pivot point for prying.	3	**36**	Rubber protection can be easily replaced when they fall off after time of use.
Core removal during roll change	The wear-out occurs on the notch designed for creating the initial gap for the removal process.	May take more effort to remove the core	4	Rubbing between the pry bar and the slot	3	Add speical coating on the sharp end of the pry bar and the created notch on the chuck.	3	**36**	Sharpen the sharp end of the pry bar and reshape the notch to keep the proper tolerance.
Safety of applying pry bar for core removal by the operator.	Potential risk of bar slipping from hands.	It may cause injury to operator's hand or damage the slitting machine.	7	There is not enough friction between the pry bar and hands.	4	Add rubber grips on the pry bar where the operator holds.	3	**84**	Rubber grips are replacable when they wear out.
Modified chuck can be used for all MB slitting machines and cores.	New cores may have trouble being removed from the chuck by the pry bar.	More time and manpower can be consumed during the manual removal process.	6	The new cores do not have enough tolerance due to the new manufacture.	3	The slot of new cores can be remachined to fit the keyways on the chuck.	3	**54**	Lubricating agent can be still spplied for the new cores to fit in the current process.
New notch can be manufactured on the chuck if the existing notch loses its shape after it wears out.	Vibration occurs when the motors moves at high rotational speeds.	Potential risk of damaging the siltting machine and creating noise.	6	The additional notch on the chuck can unbalance the core in rotation.	2	Rebuild the whole shoulder of the chuck and recreate the new notch to maintain the integrity of the chuck.	3	**36**	Regular maintenance can be done to reduce the abrasion on the notch.

The function regarding the safety of the operator applying pry bar core removal process yields the largest number of RPN. Therefore, FMEA result emphasizes safety and integrity when designing the core removal process, which meets our primary design requirement of our project. Due to potential risk of the pry bar slipping and causing operator injury and machine damage, a rubber grip can be attached to the pry bar where hand can hold. In addition, a recommended action of this component design is that rubber grip can be replaced when it wears out after period of use.

Overall, frequent core removal process can weaken the material strength of the chuck and cause continuous wear-out on the notch and shoulder of the chuck. Therefore, recommended actions for other functions of our design are all proposed based on the current design process, in order to make continuous improvement on the design. The benefits of recommended actions are aimed at easy replacement for wear-out components so that the process improvement design can meet the company's expected production goal of reducing the time waste during the manufacturing process, and maximizing the production efficiency.

2.6 Cost Analysis

The cost analysis is based on the manufacturing cost of modifications on the chuck and pry bar, which includes the rubber coating on the sharp pry bar tip and the edges of the chuck's shoulders as well as the material of the rubber grips on the pry bar.

It is recommended to modify both chucks on one slitting machine in order to reduce the possibility of core getting stuck on one end. Therefore, the price of the notch manufactured on the shoulder edge is $192.70, which is the manufacturing cost with labour cost included for both chucks. At the beginning, the chucks on the three multi-barrier slitting machines will be modified for overall performance testing.

The cost information of the rubber handgrip is obtained from McMaster-Carr [14]. The handgrip chosen is 27/32'' to 7/8'' in outer diameter and 6'' in overall length, which is slightly larger than the diameter of the pry bar.

Since the diameter of the shoulder of the chuck is 5.960'' [15], a total length of rubber attached around the shoulder of the chuck is calculated as $\pi \cdot 5.960''$ to be 18.724''. The cost of Plasti-Dip required for metal is $12.43 per 11 ounces [10]. Because the round grip and rubber coating applied on the chuck shoulder and pry bar tip can be easily done by the operator, we assume that the labour cost for them is negligible.

According to our final design selection of modification of chuck and pry bar, the cost for our design per multi-barrier slitting machine can be summarized as shown in TABLE VI.

TABLE VI: SUMMARY OF THE COST OF THE FINAL DESIGN

Design components	Size	Cost
Modification of the chuck		
Notch on the shoulder edge	1''x ¼''x 3/8''	$96.35x 2= $192.70 [16]
Rubber on the shoulder	¼''x 18.724''	$12.43
Modification of the pry bar		
Round grips	27/32''- 7/8''x 6''	$13.79/6= $2.30
Coating on the sharp end	1''x ¼''x 3/8''	$12.43
	Total	$219.86

The total cost for our design is approximately $219.86 for one MB slitting machine, which is within the proposed budget for this project $2000. Since there are six slitting machines for multi-barrier production, the proposed budget can be adequate for improving the core removal process for all of them.

3. Conclusion and Recommendations

In conclusion, our team was tasked with a problem that dealt with removal of steel cores from Winpak's slitting machines. The steel cores are mounted on the slitting machines by way of the chucks. There is a tight fit between the cores and chucks and therefore, 50% of the time the steel cores get stuck on one of the chucks. This creates delays and safety hazards. The current method for core removal is dangerous and causes damage to the chucks and cores. The method also creates a safety risk for the operators. Winpak has contracted our team to design a solution that allows Winpak employees to safely and efficiently remove the steel core from the chuck without damaging the slitting machine components.

After going through a rigorous design procedure, our team has come to a solution that is a modification of the current process. The Winpak employees currently use a steel pry bar and a square tube in order to remove the cores. Our solution uses these same components. In addition to these components we made a modification to the chuck. We cut a slot out of the shoulder, which the cores rest up against, the size of the tip of the pry bar. This allows the operators to get better leverage. Creating the initial gap between the core and the chuck shoulder was always the hardest and most dangerous part of the process. This cut out creates that gap and gives the pry bar better grip. In addition to the slot, we decided to add a rubber grip to the pry bar. This rubber grip goes where the operator typically holds the pry bar when removing a core. The rubber creates a better grip for the operator and therefore addresses the safety concern. The final component to our solution is that we coated the tip of the pry bar with rubber. This decreases the damage done to the cores and chucks. There is no longer steel on steel contact and therefore less wear and tear. This solution has already begun the testing phase.

Our team also has two recommendations for the future to improve this process even more. We did not include these as part of our solution because they were not within our budget. Our first recommendation is that Winpak should consider implementing a regular cleaning of the steel cores. Dirt builds up on the insides of the cores which makes the fit between the cores and chucks even tighter. This past summer Winpak hired students to clean the insides of the cores, and according to the operators it made a difference until the dirt built up again. Implementing cleaning of the cores would reduce the number of cores getting stuck.

The other recommendation that our team has proposed for Winpak is to consider changing to expandable chucks for their steel cores. These types of chucks are already used for their cardboard cores but would also help for the steel cores. With expandable chucks, the cores would never get stuck and therefore a lot of time could be saved. These chucks are more expensive than the current chucks but when it comes time to replace the old chucks considering expandable chucks would be advisable. Even with the extra cost of the expandable chucks, Winpak would benefit. The decreased waste time due to stuck cores would be eliminated and therefore Winpak could make more money. Our solution will work but these suggestions would improve the process even more.

The above recommendations would improve the core removal process further but not necessary, since our proposed design works well. From the testing that has been done, it has been found that the operators are satisfied with the modifications made to the process. The current core removal process takes 3-30 minutes depending on how severely stuck the core gets. With the modification, the process time has been decreased to 3-5 minutes. The time reduction will increase the amount of materials processed in a shift. It was estimated by Winpak that one more roll of material processed per shift for annual operation will increase the revenue by $16 million. The design outlined in this report is feasible and justified to be implemented.

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Appendix A

Table of Contents

List of Figures

A. Introduction

The team researched on different mechanical and electrical components and how they can be used to generate a solution for this design project. For example, the team looked at how a hydraulic pump can be used in our design to bring about a solution. Patents were also searched. These also help in concept generation. We then went through a brainstorming phase, in which each one of us tried to generate concepts.

A.1 External Research

The project that our team is working on is a unique one and as such it will be difficult to find information about how others have solved similar problems. For this reason, our team focused on the main functions required from the solution to be successful in our research. The main function of the device is forcing the steel core off the chuck. Online research was used to generate ideas on how to tackle the problem. These websites contained various mechanical components that would be helpful in our design.

One website that was very helpful for coming up with ideas was McMaster-Carr [1]. This site is a database of a lot of standard parts that are used in the building and manufacturing fields of work. The website has everything from plumbing and electrical components to power transmission components. Components that are of interest to us, are hydraulic cylinders and car jacks. These devices can be used to generate the force needed to remove the steel core from the chuck. McMaster-Carr is also helpful for getting some pricing of the standard components. The site has pricing for everything and while that may not be our exact pricing, it is helpful for getting a general idea if that solution will be within the budget.

Another site that had some useful information was Ergonomic Partners [2]. Ergonomic Partners sells various lift systems used in manufacturing processes. Pictures and videos from this site assisted in generating ideas on how to grip to steel components. To grip the cores, we could use suction or a clamping mechanism. This will be key depending on our solution.

Another website that we used for brainstorming is the TRIZ40 site [3]. This site utilizes the brainstorming technique TRIZ. TRIZ generates solutions to contradictions within designs. This technique utilizes patents. With this site we were able to select the customer requirements that contradicted each other and find possible solutions. One of the contradictions that we searched is between weight of a stationary object and ease of operation. One of the useful solutions to this contradiction is to have one object perform multiple functions.

We also did some patent searches in order to get some ideas. Patents often give us new ideas on how to solve specific problems. Slight modifications can be done to the patented work to allow parts of the patent design to work within the new design we are developing.

One patent that we found is an air chuck mechanism for a slitting machine. This is a modified version of a chuck used in a slitting machine. The air chuck has a grip jaw on the surface as shown in Figure A.1. The steel core slides onto the chuck easily and using air pressure the grip jaw is pushed out causing the grip jaw to have a firm grip on the inner wall of the steel core and to secure the steel core in place while it unrolls material. To remove the steel core from the chuck, the air pressure is removed which causes the grip jaw to retract back into the chuck [4].

[redacted]

Figure A.1: An air chuck for a roll slitting machine (modified from Rollexe) [5].

Along with research we also had close contact with Winpak employees. The employees are the ones that have to deal with the issues every day and so their input is very important. Talking with operators helped generate ideas and also see the flaws of the ideas we had generated. Every meeting we had at Winpak included one of the operators, which was very useful.

A.2 Brainstorming

Once each of the team members had done some external research, we tried to generate some ideas. Based on the problem that is to be solved, we initially came up with a few important functional requirements of our design. We then tried to think of ways that could help us meet those specific functional requirements. The design should be able to perform certain functions which are listed below:

1. Remove the core from the chuck
2. Eliminate any risk of hand injury
3. Reduce/eliminate any damage to the chuck
4. The tool material must be safe to use on the shop floor

In order to develop design alternatives, our team used a function means table. Based on the function, our team came up with different design alternatives, by researching on the availability of devices that are intended to serve the same functions for the same kind of user. TABLE A.1 shows the important functional requirements of the design and how those requirements could be achieved.

TABLE A.1: THE FUNCTION OF THE DESIGN AND ALTERNATIVE MEANS TO ACHIEVE THESE FUNCTIONS

Function	Means to achieve the function				
Remove core from chuck	Hydraulic setup like a car jack	Mechanical force	Magnetize chuck and core to create same poles that repel and create a frictionless gap	Greasing the space between chuck and core with lubricant i.e. carbon graphite	Spacer or plate between chuck and core
Eliminate hand injury	Rubber padding on tool to improve grip	Hands-free device			
Reduce damage to chuck and core	Rubber padding	Foam padding	Gel cushioning		
Tool Material	Stainless Steel	Plastic	Composite		

Based on the ideas mentioned in TABLE A.1, the team came up with six concepts. These concept are as follows:

Concept A – Drilling a hole into the chuck and modifying the pry bar

Concept B – New prying tool design

Concept C – Force gun

Concept D – Linear actuator separator

Concept E – Scissor Jack used together with a spacer plate

Concept F – Hydraulic lifter used together with a spacer plate

The following sections give a more detailed description of the above mentioned concepts.

A.2.1 Concept A – Drilling a Hole into the Chuck and Modifying the Pry Bar

The steel core has two key ways 180° apart. Only one key way is needed to fix the steel core to the chuck. This concept involves modifying the chuck and the pry bar that is currently used. A hole will be drilled into the chuck at the location of the unused keyway and a pry bar will fit into this hole and be used to push the steel core out of the chuck as seen in Figure A.2. For the pry bar, silicon or hard plastic material will be used to coat the end that goes into the hole that is drilled into the chuck and an ergonomic grip will be designed to serve a handle for the pry bar.

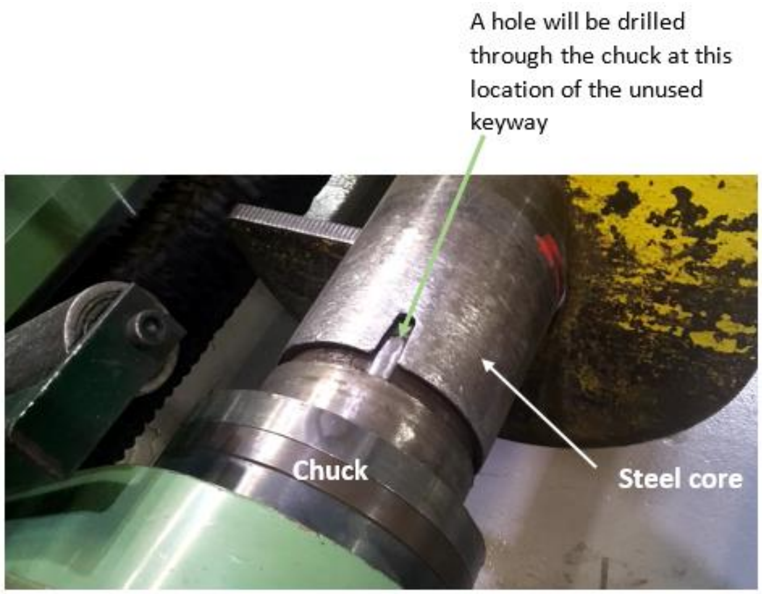

Figure A.2: A hole will be drilled into the chuck in the location of the free keyway on the other side of the steel core [6].

A.2.2 Concept B – New Prying Tools Design

As shown in Figure A.3, a pry bar is used to create a space between the core and the chuck. The core is then pushed by pivoting the pry bar on the metal tube. Since there are three steps for the removal process and two different tools are being used, the concept of combining the two tools in a single tool was proposed in our brainstorming session. Therefore, if the initial gap can be created without using a pry bar, the damage caused to the chuck by the pry bar during the operation can be prevented. Combining the two tools can also be safer. The operator will have to push the handle away from him rather than pulling it towards (as in the current process).

As seen Figure A.3, there are two keyways on the core. One of them is locked to the key on the chuck and the other one is left unused. The purpose of having two keyways on each end of the core is to provide convenience to the operators with alternative keyway to lock the core to the chucks without rotating the core over a large angle to aligning the key with keyway.

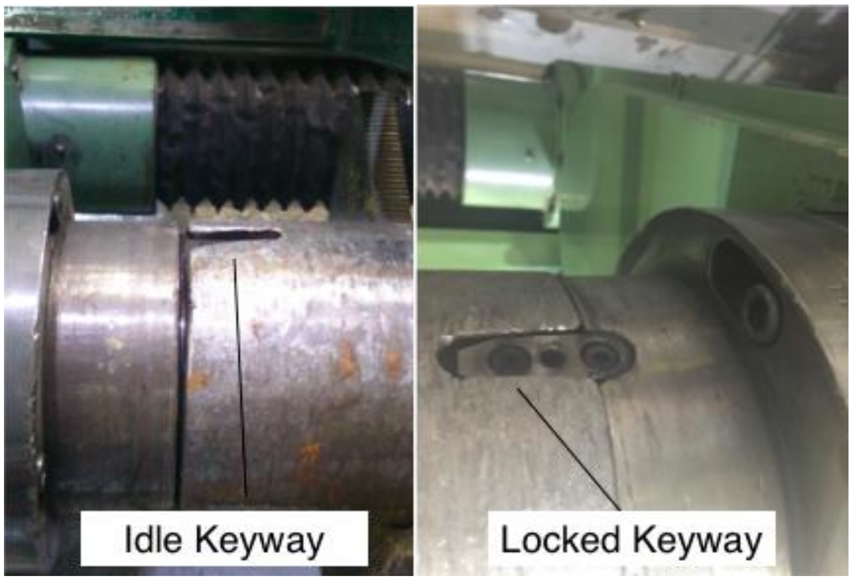

Figure A.3: Idle and locked keyways of the core [7]

During our concept brainstorming, we took advantage of the existing idle keyway on the core. This concept deals with designing a welded prying tool of three–sided structure with pin connected. The schematic designed prying tool is shown in the Figure A.4.

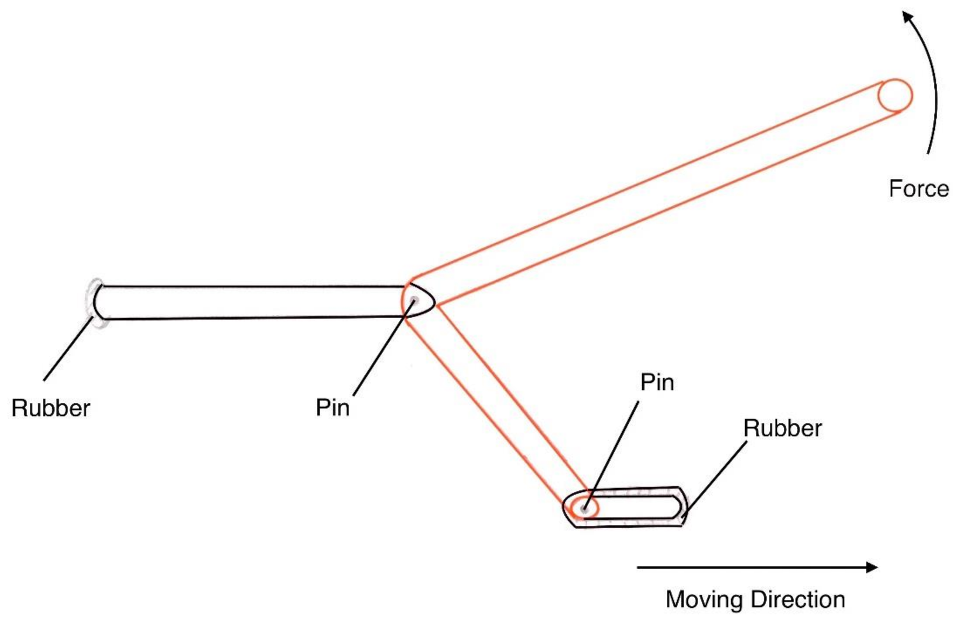

Figure A.4: A schematic of the prying tool design

The red component of the tool ('L' Shape) is a welded part. The longer side is the handle, where the operator can apply an upward force. The other two black parts are pin connected to the welded part. The longer horizontal black piece is a support, which has a stiff rubber tip pivoted to the sides of the slitter so as to have a secure griping. The shorter black piece is designed as the rigid bar that occupies the unused keyway on the core. The rigid bar is designed to of the exact size of the key surrounded by a rubber ring, which can easily fit into the keyway and maintain the traction without causing damage when the handle is pushed upwards.

During the core removal process, the smaller black part should be fully inserted into the keyway of the core and the pivot point of the longer black part is attached to the chuck horizontally as a fixed point when the force is applied. When the core is gradually pushed off the chuck, the operator can release the handle and adjust the location of the pivot point close to the keyway until he can continuously push the core from the chuck. Figure A.5 shows the operation of the new prying tool design, and the pivoting of the tools to the sides of the slitting machine.

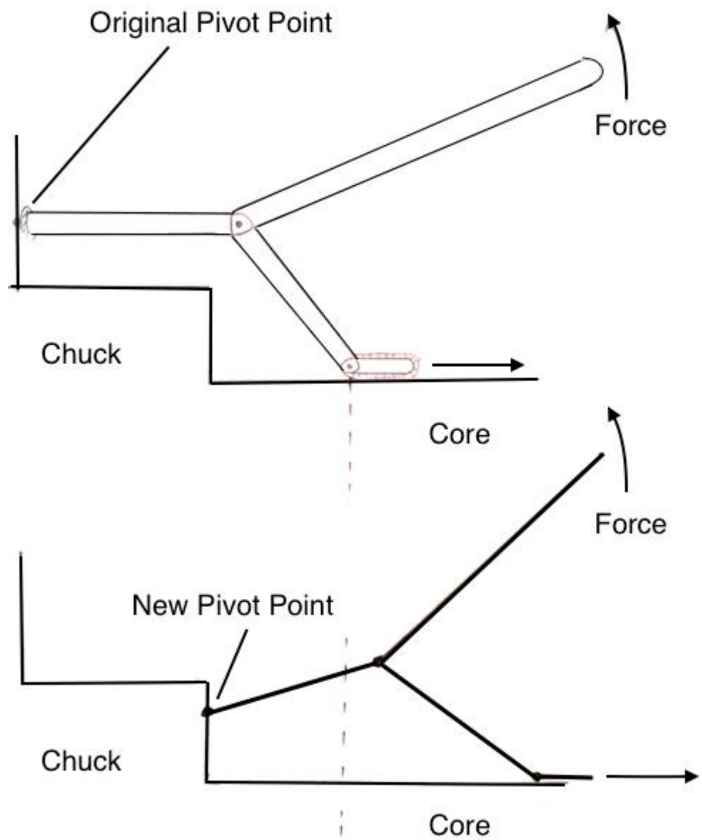

Figure A.5: The working of the new prying tool design

A.2.3 Concept C – Force Gun

Figure A.6 shows the force gun. The force gun uses spring force to release the steel core from the chuck. The operator will need to set the *swing arm* first before operation. The operator pushes the *push button* forcing the *plate holding release pin* to move back. The *swing arm* is now free to move back and forth because the *release pin* is no longer holding it in place. The operator now pushes the *swing arm* back against the *flat plate* and *spring* while still pushing on the *push button*. Once the *swing arm* is behind the *release pin*, the operator releases the *push button* to secure it in place. The gun is then place on the steel core with the *gap widener* fitting into the unused keyway shown in Figure A.3. The operator then pushes on the *push button* causing the *swing arm* to swing and hit the chuck of the machine. The force from the *spring* is transmitted to the *swing arm* which is transmitted to the *gap widener*. This force is what forces the steel core off the chuck.

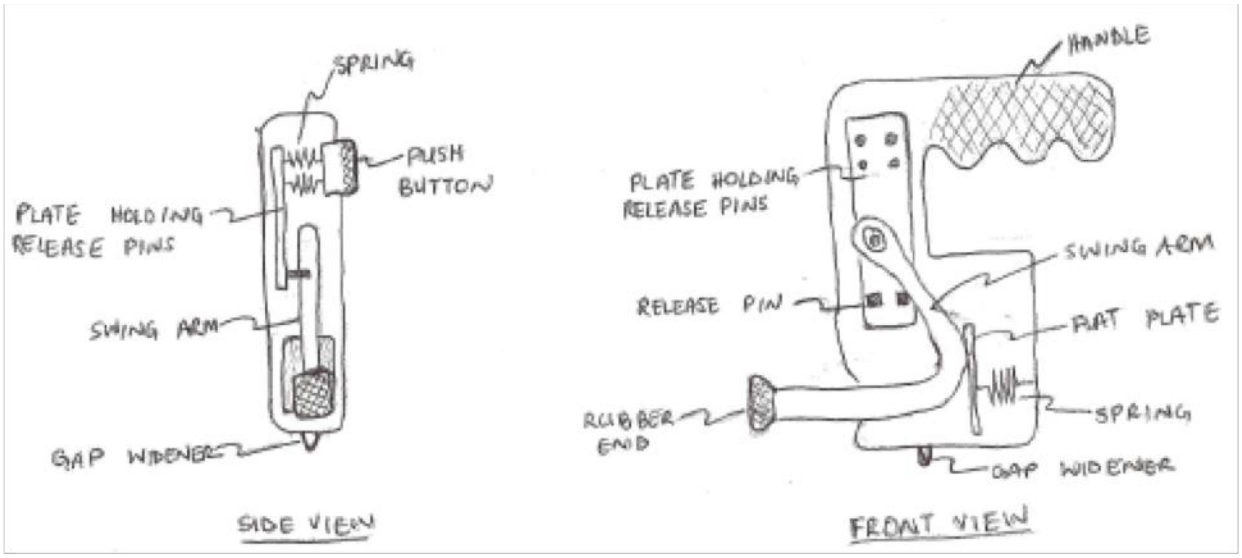

Figure A.6: Sketch of the Force Gun

A.2.4 Concept D – Linear Actuator Separator

Figure A.7 shows a linear actuator separator. In the pneumatic piston pusher, the *piston rod* moves left when air is forced into the *extend flow port* and the *piston rod* moves right when air is forced into the *retract flow port*. The *piston metal pin* is attached to the *piston rod* and moves freely with the *piston rod*. The *instrument body metal pin* is part of the body of the design and it is stationary. The *instrument body metal pin* and the *piston metal pin* fits into the keyway on the steel core when the *piston rod* is in the farthest position to the left. The operator forces air into the *retract flow port* and the *piston rod* and *piston metal pin* begin to move left forcing the steel core off the chuck.

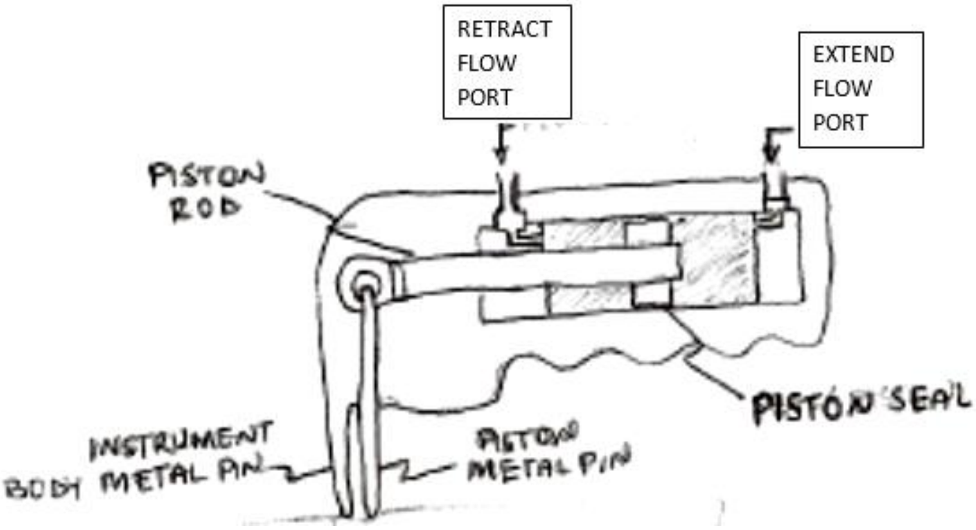

Figure A.7: A schematic of the Linear Actuator Separator

A.2.5 Concept E – Scissor Jack and Spacer Plate

Another concept that we came up with in our brainstorming sessions involves the use of a typical scissor jack used to lift a vehicle when changing a tire. Figure A.8 is an image of a typical scissor jack. The way this device works is by turning the threaded rod. There is a handle attachment that hooks into the O-ring seen in the image and this is used to turn the treaded rod. When the threaded rod is turned it pulls the legs of the scissor jack in forcing the end of the jack to move away from the threaded bar. This is how this device creates force. Due to the fact that a scissor jack, like the one in Figure A.8, can be used to lift a car, we are confident that this device will generate enough power to push the core off of the chucks.


Figure A.8: This is an image of a typical scissor jack [8].

The method that we envision using the scissor jack in can be explained using Figure A.9.

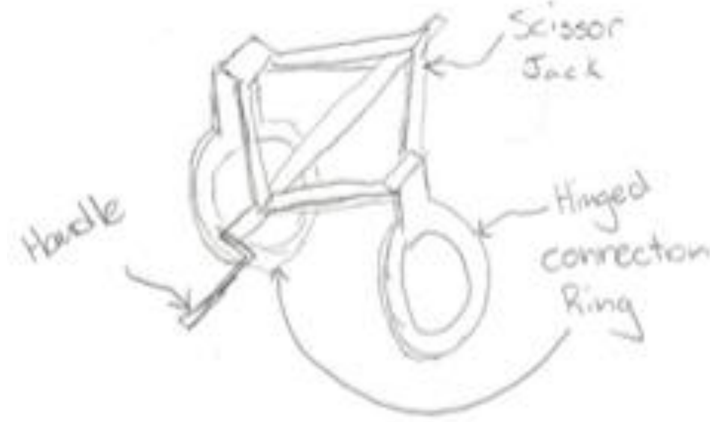

Figure A.9: The use of a scissor jack to remove the core from the chuck

Figure A.9 shows the scissor lift connected to two, hinged connection rings. These hinged connection rings are what would be used to connect the scissor lift to the slitting machine and steel core. One ring would be secured onto the slitting machine. The other connection ring would fit tightly on the steel core. When the handle is turned the two connection rings would be forced apart. Therefore dislodging the core from the chuck.

A concept of what the hinged connection ring looks like is seen in Figure A.10. At the hinged point the plates are connected but still are allowed to turn and open up. The bolt location is where a bolt would be used to hold the ring from opening when in place. This ring needs to fit tightly around the steel core so as to ensure it grips it properly. Lining the inside with rubber and creating a notch to fit in the unused keyway on the steel core will also help create a better grip.

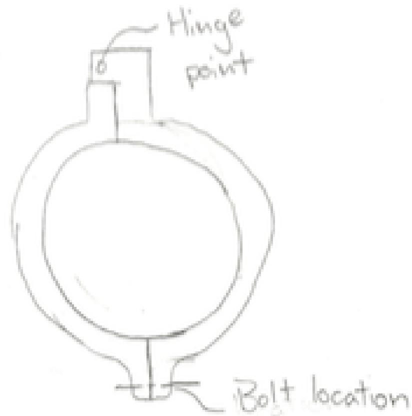

Figure A.10: This image shows a concept for the hinged connection ring used to connect a scissor jack to the slitter and core

A.2.6 Concept F – Hydraulic Jack and Spacer Plate

This concept is similar to concept E. This concept uses a hydraulic hand pump instead of the scissor jack to remove the core from the chuck. Some of the advantages of using a hydraulic hand pump over the scissor lift are that the hydraulic pump can work better in all situations, for example, in cases when the core is completely jammed onto the chuck. The hydraulic pump is easy to use and can often give higher power than the scissor lift. Figure A.11 shows the hydraulic hand pump that can be used to remove the core from the chuck.

[redacted]

Figure A.11: Single-speed hydraulic hand pump [9]

Just like the scissor jack in the previous concept, the hydraulic pump would be mounted in a similar fashion. The same spacer design will also be used for this concept.

A.3 Summary

This section explains the process of concept generation. Research was conducted to generate ideas after the problem had been clearly defined. This included looking at patents as well as standard components. Close contact with the operators was also key to generating ideas. The results from going through this process have left us with six feasible solutions: the chuck modification concept, the new prying tool, the force gun, the linear actuator separator, the scissor jack and hydraulic concept. The next step in the design process is to narrow the concepts down to the ideal solution.

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Appendix B

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List of Tables

B. Introduction

Once enough concepts were generated, the team began to narrow down the number of the concepts and pick the best for the next design phase, in which we would further analyze the selected concepts to check their feasibility. We first went through concept screening to select the best ideas. Some of the ideas could be combined to come up with a better idea. We then weighed the criteria to determine how important a given criteria was to the design. Based on the weight of the criteria, we came up with a concept scoring matrix which enables us to select the best concepts from the initial six concepts.

B.1 Concept Screening

The current core removal process was used as a reference and was compared to the new concepts. For a given selection criterion, a concept is given a plus (+), zero (0) or a minus (-) if that concept is better, same or worse, respectively, compared to the current process. TABLE B.1 shows the results of the concept screening stage.

TABLE B.1: SCREENING OF THE CONCEPT AGAINST THE CURRENT CORE REMOVAL PROCESS

	Concept Variants						
Selection Criteria	**A**	**B**	**C**	**D**	**E**	**F**	**Reference**
Portable	0	0	0	+	0	0	0
Safe	+	+	+	+	+	+	0
Easy to Use	+	0	-	-	+	+	0
Efficient	+	0	-	-	+	+	0
Easy to handle	+	+	+	+	0	0	0
Inexpensive	-	0	-	-	-	-	0
Durable	+	0	+	+	+	+	0
Easy to manufacture	0	-	-	-	-	-	0
Minimal force required	0	0	+	+	+	+	0
Effective	+	0	0	+	+	+	0
Lightweight	0	0	-	0	-	-	0
Pluses	6	2	4	6	6	6	
Zeros	4	8	2	1	2	2	
Minuses	1	1	5	4	3	3	
Net	5	1	-1	2	3	3	
Rank	1	5	6	4	2	3	
Continue?	yes	no	no	yes	yes	yes	

From the result of concept screening, we decided carry forward concepts A, D, E and F. However, we would consider the eliminated concepts in the later phases in the need be so.

B.2 Criteria Weighting Matrix

We compared one criterion to the other to determine the importance of the criteria. The criteria that ended up with the highest weight are the most important criteria in the design, whereas the criteria that had the lowest weight are the least important. TABLE B.2 shows the results of the criteria weighting exercise.

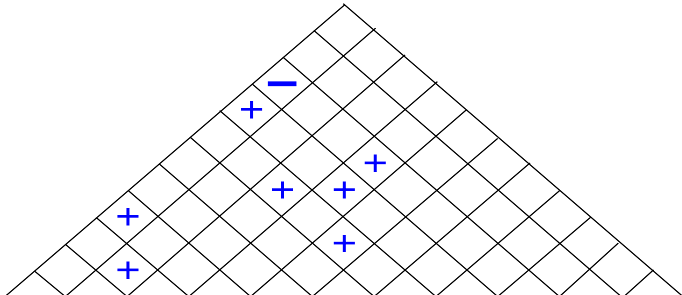
TABLE B.2: WEIGHTING THE CRITERIA AGAINST EACH OTHER TO DETERMINE THE IMPORTANCE OF ONE CRITERIA OVER THE OTHER

Criteria		Portable	Safe	Easy to use	Efficient	Easy to handle	Inexpensive	Durable	Easy to manufacture	Minimal force required	Effective	Lightweight
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
A	**Portable**		B	C	D	E	F	A	A	I	J	K
B	**Safe**			B	B	B	B	B	B	B	B	B
C	**Easy to use**				C	C	C	C	C	I	C	K
D	**Efficient**					D	D	D	D	I	J	K
E	**Easy to handle**						E	E	E	I	J	K
F	**Inexpensive**							G	F	I	J	K
G	**Durable**								G	I	J	K
H	**Easy to manufacture**									I	J	K
I	**Minimal force required**										J	I
J	**Effective**											J
K	**Lightweight**											
Total Hits		2	10	7	5	4	2	2	0	8	8	7
Weightings		0.2	1	0.7	0.5	0.4	0.2	0.2	0	0.8	0.8	0.7

From the results, it can be seen that safety is the most important criterion, followed by effective and minimal force required which are equally important. Manufacturability ended up being the least important criterion.

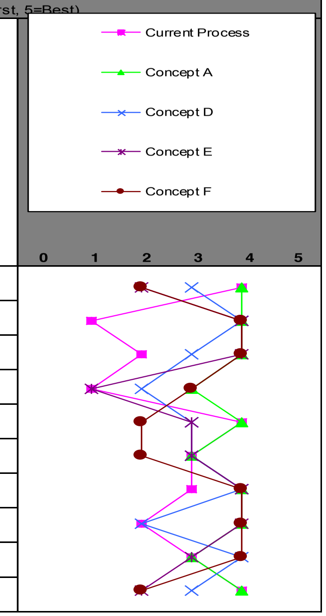
B.3 House of Quality

A House of Quality (HOQ) was used to determine how the team will be able to meet the client needs. The relationship between the functional requirements was also determined using the HOQ (this can be seen on the roof of the HOQ). The concepts were then rated based on each customer requirement. This rating was then used in the concept scoring matrix to select the best concept. Figure B.1 shows the House of Quality for the concepts that were carried forward from the concept screening phase. From the HOQ, it can be seen that the top three important criteria were the time it takes to remove the core, the size in terms of the space the new design occupies and the weight of the design, respectively. Whereas, the three least important criteria were manufacturing cost, cost of design material and the life cycle to failure respectively.



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column # →	1	2	3	4	5	6	7	8	9	10	11	Current Process	Concept A	Concept D	Concept E	Concept F
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▲	▼	▼	▼	▼	▼	▼	▲	▼	▲					
				Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	cost of design materials	number of ways to transport	weight of the design	manufacturing cost	total force required	time it takes to remove steel core	number of ways to cause damage	size of the design	life cycle	training requirement	probability of success	Current Process	Concept A	Concept D	Concept E	Concept F
1	9	3.6	0.2	Portable		Θ	Θ			O		Θ				4	4	3	2	2
2	9	18.2	1.0	Safe		▲	O				Θ			O		1	4	4	4	4
3	9	12.7	0.7	Easy to Use	▲		▲			O				Θ		2	4	3	4	4
4	9	9.1	0.5	Efficient						Θ					Θ	1	3	2	1	3
5	9	7.3	0.4	Easy to handle			▲			O		Θ		▲		4	4	3	3	2
6	9	3.6	0.2	Inexpensive	Θ			Θ				O	Θ			3	3	3	3	2
7	9	3.6	0.2	Durable	O						▲		Θ			3	4	4	4	4
8	9	14.5	0.8	Effective					O	Θ			▲		Θ	2	4	2	4	4
9	9	14.5	0.8	Minimal force required					Θ	▲	O		▲			3	3	4	3	4
10	9	12.7	0.7	Lightweight	▲	Θ	Θ					Θ				4	4	3	2	2
				Target or Limit Value	$1,000	>1	<22kg	$1,000	<200 N	5 minutes	0	85" X 216"	>2000 uses	5 minutes	100%					
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	2	6	4	3	8	7	5	3	5	2	8					
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9					
				Weight / Importance	69.1	165.5	221.8	32.7	174.5	298.2	210.9	223.6	94.5	176.4	212.7					
				Relative Weight	3.7	8.8	11.8	1.7	9.3	15.9	11.2	11.9	5.0	9.4	11.3					

Competitive Analysis (0=Worst, 5=Best)



Legend

Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
—	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

Figure B.1: The House of Quality used to tabulate how each client need would be achieved. It also shows the concept rating based on each of the functional requirement.

B.4 Concept Scoring Matrix

Concept scoring was performed once the weighting of the criteria was obtained. The concept rating was obtained from the HOQ. The weight was multiplied by the rating and the score was summed up to get a total score. The higher the score, the better the concept is. TABLE B.3 shows how the concepts scored against each other.

TABLE B.3: CONCEPT SCORING USING THE WEIGHTING OF THE CRITERIA TO PICK THE BEST CONCEPT THAT WILL LATER BE ANALYZED IN THE NEXT PHASE OF THE PROJECT

		Concepts							
		A		D		E		F	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Portable	**0.2**	4	0.8	3	0.6	2	0.4	2	0.4
Safe	**1**	4	4	4	4	4	4	4	4
Easy to Use	**0.7**	4	2.8	3	2.1	4	2.8	4	2.8
Efficient	**0.5**	3	1.5	2	1	3	1.5	3	1.5
Easy to handle	**0.4**	4	1.6	3	1.2	3	1.2	2	0.8
Inexpensive	**0.2**	3	0.6	3	0.6	3	0.6	2	0.4
Durable	**0.2**	4	0.8	4	0.8	4	0.8	4	0.8
Easy to manufacture	**0**	3	0	2	0	2	0	2	0
Minimal force required	**0.8**	3	2.4	4	3.2	3	2.4	4	3.2
Effective	**0.8**	4	3.2	2	1.6	4	3.2	4	3.2
Lightweight	**0.7**	4	2.8	3	2.1	2	1.4	2	1.4
Total Score		20.5		17.2		18.3		18.5	
Rank		1		4		3		2	
Continue?		yes		no		yes		yes	

From the results, it can be seen that concepts A, E and F were amongst the top 3 concepts. The team decided to carry forward those 3 concepts to the next phases. Since concepts E and F are almost similar, one of them will be finally eliminated once a more detailed analysis is performed in the next project phase.

B.5 Cost Analysis

In this project, the cost can be divided into three major parts. They are material cost, equipment cost and manufacturing cost. The proposed budget for this project is $2000. TABLE B.4 shows a rough cost estimate for the top three concepts.

TABLE B.4: A ROUGH COST ESTIMATE FOR THE CONCEPTS THAT ARE TO BE CARRIED FORWARD TO THE NEXT PROJECT PHASE

Concept	Material Cost ($)	Equipment Cost ($)	Manufacturing Cost ($)
A	N/A	N/A	Not Specified
E	Depends on the thickness of the plate	$32.24 [1]	Not Specified
F	Depends on the thickness of the plate	$326.49 [2]	Not Specified

For concept A, a slot and corresponding hole are to be drilled onto the chuck. Therefore, no necessary material cost is generated under this circumstance but there will be a manufacturing cost of milling the hole and slot and the cost will not go beyond budget.

For Concepts E and F, since there will be similar design principle with an additional equipment and a spacer plate, the cost of the equipment will be compared to show the preference from the cost perspective. It is obvious that scissor jack is much cheaper than the hydraulic lifter. Regarding the material cost and manufacturing cost, it will be similar for both designs since a plate will be used for creating initial gap.

B.6 Summary

Our team utilized concept screening and scoring to narrow our six concepts down to the best three. These three are the modification to the chucks, the hydraulic pusher and the scissor jack pusher. The scissor jack and the hydraulic ideas are similar so they were considered together.

References

[1] Amazon. (2015). OTC 4002 Single-Speed Hydraulic Hand Pump [Online]. Available: http://www.amazon.ca/OTC-4002-Single-Speed-Hydraulic-Hand/dp/B00063UNFS/ref=sr_1_10?ie=UTF8&qid=1445910426&sr=8-10&keywords=hydraulic+pump. [Oct 25, 2015].

[2] Amazon. (2015). Powerbuilt 640819 Mechanical Scissor Jack [Online]. Available: http://www.amazon.ca/Powerbuilt-640819-Mechanical-Scissor-Jack/dp/B002INP6QU/ref=sr_1_13/191-6639692-9682008?ie=UTF8&qid=1445910305&sr=8-13&keywords=car+jack. [Oct 25, 2015].

Appendix C

C. Project Scheduling

Various project management tools were used throughout this project, in order to maintain organization, group cohesiveness, and a continuous sense of forward progress. One of the project management tools used was a Gantt chart. The Gantt chart provided a detailed schedule our team followed. The project commenced on September 10, 2015 and was completed on December 7, 2015. The completion of each phase is considered to be a milestone for the project. The project has a total duration of 91 days.

Figure C.1 provides the detailed project schedule, which shows the duration in days, the precedence, the early and late start dates and early and late finish dates. It also tabulates the relationship types for each task. The project has two relationship types: Finish-to-Start (FS) and Finish-to-Finish (FF). The tasks start and proceed according to their relationship type.

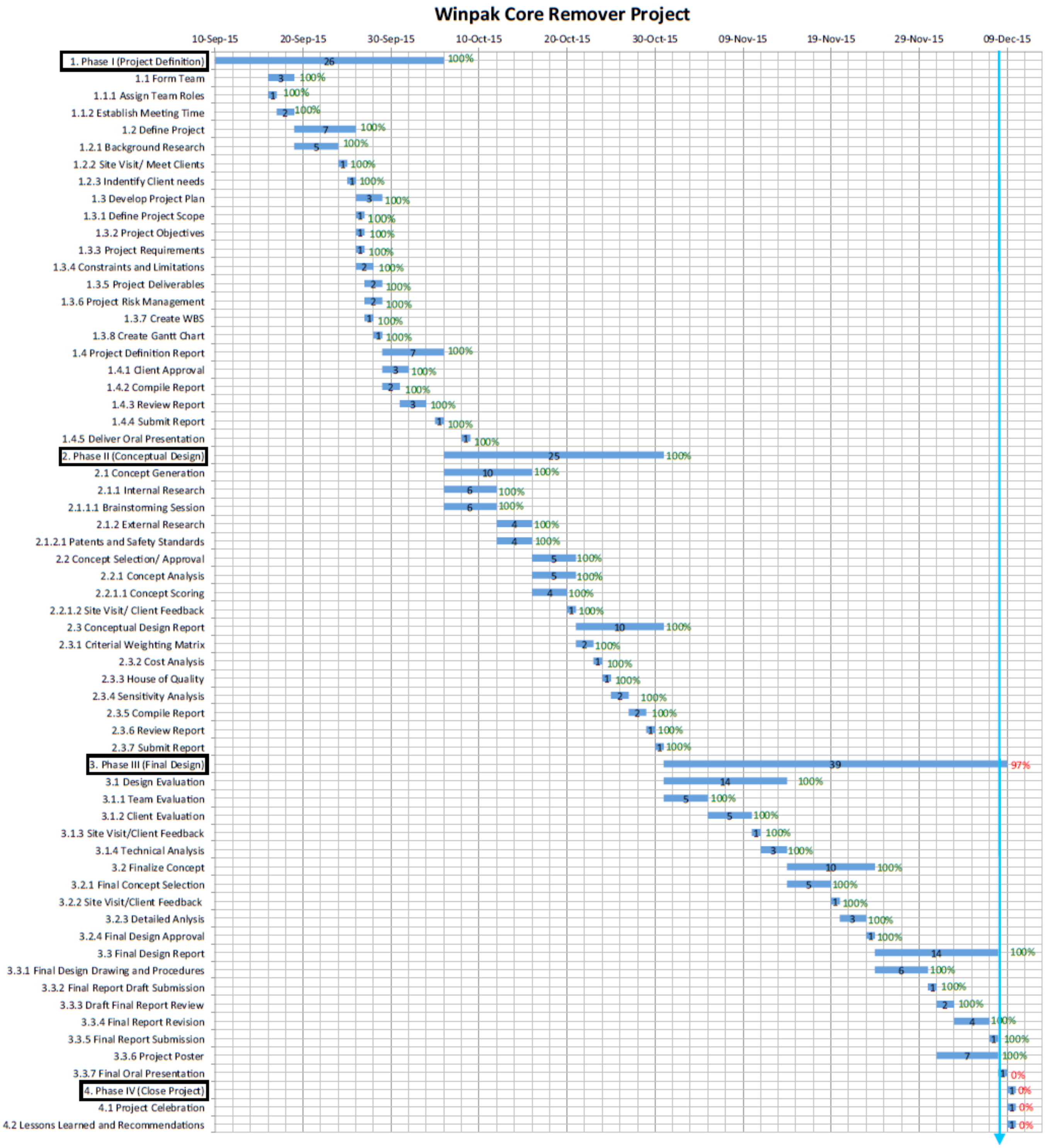


Figure C.1: Gantt chart

TABLE C.1 shows the precedence of each task and also the start and finish dates, duration, and relationship type.

TABLE C.1: DETAILED TASK SCHEDULE

Task No.	Tasks	Duration (days)	Precedence Task No.	Relationship Type	Early Start Date	Early finish Date	Late Start Date	Late Finish Date
1	Phase I (Project Definition)	26			10-Sep-15	04-Oct-15	10-Sep-15	05-Oct-15
1.1	Form Team	3			16-Sep-15	18-Sep-15	16-Sep-15	18-Sep-15
1.1.1	Assign Team Roles	1	Start	FS	16-Sep-15	16-Sep-15	16-Sep-15	16-Sep-15
1.1.2	Establish Meeting Time	2	Start	FS	17-Sep-15	18-Sep-15	17-Sep-15	18-Sep-15
1.2	Define Project	7			19-Sep-15	25-Sep-15	19-Sep-15	25-Sep-15
1.2.1	Background Research	5	1.1	FS	19-Sep-15	23-Sep-15	19-Sep-15	23-Sep-15
1.2.2	Site Visit/ Meet Clients	1	1.1	FS	24-Sep-15	24-Sep-15	24-Sep-15	24-Sep-15
1.2.3	Indentify Client needs	1	1.2.2	FS	25-Sep-15	25-Sep-15	25-Sep-15	25-Sep-15
1.3	Develop Project Plan	3			26-Sep-15	28-Sep-15	26-Sep-15	28-Sep-15
1.3.1	Define Project Scope	1	1.2.3	FS	26-Sep-15	26-Sep-15	26-Sep-15	26-Sep-15
1.3.2	Project Objectives	1	1.2.3	FS	26-Sep-15	26-Sep-15	26-Sep-15	26-Sep-15
1.3.3	Project Requirements	1	1.2.3	FS	26-Sep-15	26-Sep-15	26-Sep-15	26-Sep-15
1.3.4	Constraints and Limitations	2	1.2.3	FS	26-Sep-15	27-Sep-15	27-Sep-15	28-Sep-15
1.3.5	Project Deliverables	2	1.3.3	FS	27-Sep-15	28-Sep-15	27-Sep-15	28-Sep-15
1.3.6	Project Risk Management	2	1.3.3	FS	27-Sep-15	28-Sep-15	27-Sep-15	28-Sep-15
1.3.7	Create WBS	1	1.3.3	FS	27-Sep-15	27-Sep-15	27-Sep-15	27-Sep-15
1.3.8	Create Gantt Chart	1	1.3.7	FS	28-Sep-15	28-Sep-15	28-Sep-15	28-Sep-15
1.4	Project Definition Report	7			29-Sep-15	05-Oct-15	29-Sep-15	05-Oct-15
1.4.1	Client Approval	3	1.3.8	FS	29-Sep-15	01-Oct-15	29-Sep-15	01-Oct-15
1.4.2	Compile Report	2	1.3.8	FS	29-Sep-15	30-Sep-15	30-Sep-15	01-Oct-15
1.4.3	Review Report	3	1.4.2	FS	01-Oct-15	03-Oct-15	02-Oct-15	04-Oct-15
1.4.4	Submit Report	1	1.4.3	FS	05-Oct-15	05-Oct-15	05-Oct-15	05-Oct-15
1.4.5	Deliver Oral Presentation	1	1.4.4	FS	08-Oct-15	08-Oct-15	08-Oct-15	08-Oct-15
2	Phase II (Conceptual Design)	25			06-Oct-15	30-Oct-15	06-Oct-15	30-Oct-15
2.1	Concept Generation	10			06-Oct-15	15-Oct-15	06-Oct-15	15-Oct-15
2.1.1	Internal Research	6	1.4	FS	06-Oct-15	11-Oct-15	06-Oct-15	11-Oct-15
2.1.1.1	Brainstorming Session	6	1.4	FS	06-Oct-15	11-Oct-15	06-Oct-15	11-Oct-15
2.1.2	External Research	4	2.1.1	FS	12-Oct-15	15-Oct-15	12-Oct-15	15-Oct-15
2.1.2.1	Health and Safety Standards	4	2.1.1	FS	12-Oct-15	15-Oct-15	12-Oct-15	15-Oct-15
2.2	Concept Selection/ Approval	5			16-Oct-15	20-Oct-15	16-Oct-15	20-Oct-15
2.2.1	Concept Analysis	5	2.1	FS	16-Oct-15	20-Oct-15	16-Oct-15	20-Oct-15
2.2.1.1	Concept Scoring	4	2.1.2.1	FS	16-Oct-15	19-Oct-15	16-Oct-15	19-Oct-15
2.2.1.2	Site Visit/ Client Feedback	1	2.2.1.1	FS	20-Oct-15	20-Oct-15	20-Oct-15	20-Oct-15
2.3	Conceptual Design Report	10			21-Oct-15	30-Oct-15	21-Oct-15	30-Oct-15
2.3.1	Criterial Weighting Matrix	2	2.2	FS	21-Oct-15	22-Oct-15	21-Oct-15	22-Oct-15
2.3.2	Cost Analysis	1	2.3.1	FS	23-Oct-15	23-Oct-15	23-Oct-15	23-Oct-15
2.3.3	House of Quality	1	2.3.2	FS	24-Oct-15	24-Oct-15	24-Oct-15	24-Oct-15
2.3.4	Sensitivity Analysis	2	2.3.3	FS	25-Oct-15	26-Oct-15	25-Oct-15	26-Oct-15
2.3.5	Compile Report	2	2.3.4	FS	27-Oct-15	28-Oct-15	27-Oct-15	28-Oct-15
2.3.6	Review Report	1	2.3.5	FS	29-Oct-15	29-Oct-15	29-Oct-15	29-Oct-15
2.3.7	Submit Report	1	2.3.6	FS	30-Oct-15	30-Oct-15	30-Oct-15	30-Oct-15
3	Phase III (Final Design)	39			31-Oct-15	08-Dec-15	31-Oct-15	08-Dec-15
3.1	Design Evaluation	14			31-Oct-15	13-Nov-15	31-Oct-15	13-Nov-15
3.1.1	Client Evaluation	5	2.3.7	FS	31-Oct-15	04-Nov-15	31-Oct-15	04-Nov-15
3.1.2	Team Evaluation	5	3.1.1	FS	05-Nov-15	09-Nov-15	05-Nov-15	09-Nov-15
3.1.3	Site Visit/Client Feedback	1	3.1.2	FS	10-Nov-15	10-Nov-15	10-Nov-15	10-Nov-15
3.1.4	Technical Analysis	3	3.1.2	FS	11-Nov-15	13-Nov-15	11-Nov-15	13-Nov-15
3.2	Finalize Concept	10			14-Nov-15	23-Nov-15	14-Nov-15	23-Nov-15
3.2.1	Final Concept Selection	5	3.1.3	FS	14-Nov-15	18-Nov-15	14-Nov-15	18-Nov-15
3.2.2	Site Visit/Client Feedback	1	3.2.1	FS	19-Nov-15	19-Nov-15	19-Nov-15	19-Nov-15
3.2.3	Detailed Anlysis	3	3.2.2	FS	20-Nov-15	22-Nov-15	20-Nov-15	22-Nov-15
3.2.4	Final Design Approval	1	3.2.3	FS	23-Nov-15	23-Nov-15	23-Nov-15	23-Nov-15
3.3	Final Design Report	14			24-Nov-15	07-Dec-15	24-Nov-15	07-Dec-15
3.3.1	Final Design Drawing and Procedures	6	3.3	FS	24-Nov-15	29-Nov-15	24-Nov-15	29-Nov-15
3.3.2	Final Report Draft Submission	1	3.3.1	FS	30-Nov-15	30-Nov-15	30-Nov-15	30-Nov-15
3.3.3	Draft Final Report Review	2	3.3.2	FS	01-Dec-15	02-Dec-15	01-Dec-15	02-Dec-15
3.3.4	Final Report Revision	4	3.3.3	FS	03-Dec-15	06-Dec-15	03-Dec-15	06-Dec-15
3.3.5	Final Report Submission	1	3.3.4	FS	07-Dec-15	07-Dec-15	07-Dec-15	07-Dec-15
3.3.6	Project Poster	7	3.3.2	FS	01-Dec-15	07-Dec-15	01-Dec-15	07-Dec-15
3.3.7	Final Oral Presentation	1	3.3.6	FS	08-Dec-15	08-Dec-15	08-Dec-15	08-Dec-15
4	4. Phase IV (Close Project)	1			09-Dec-15	09-Dec-15	09-Dec-15	09-Dec-15
4.1	4.1 Project Celebration	1	3.3	FS	09-Dec-15	09-Dec-15	09-Dec-15	09-Dec-15
4.2	4.2 Lessons Learned and Recommendati	1	4.1	FS	09-Dec-15	09-Dec-15	09-Dec-15	09-Dec-15

Appendix D

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List of Figures

D. Introduction

It is important to ensure that the modifications made to the chuck do not significantly decrease the chucks strength. A significant decrease in strength could cause the chuck to not perform as expected. Finite Element Analysis (FEA) aids in confirming that the strength of the chuck is not significantly affected. It is also important to have drawings of the modification. This drawing is used to quantify the modification. This section will explain the FEA process used and display the engineering drawings of the modified chuck.

D.1 Finite Element Analysis (FEA) Methodology

SolidWorks was used to perform the FEA. SolidWorks is a very useful tool for modeling and performing general FEA. The FEA performed for this report was done with arbitrary load values due to the lack of information. The results from this analysis must only be used for comparison purposes. To begin the analysis, the models that were previously made for the current chuck used by Winpak and the modified chuck our team had proposed, were taken into SolidWorks Simulation and a static study was started. Then constraints and loads were applied. The chuck was constrained on the back surface where the chuck is bolted to the arm of the slitting machine. For the loading a torque and vertical were applied to the surface at the end of the chuck. This simulates the core fitting on the chuck while spinning with the chuck.

The next step was to create a mesh. Mesh is a key component to FEA and therefore it is important to create a good mesh. For this analysis the finest mesh was used. This increases the accuracy. An image of the mesh is seen in Figure 1.

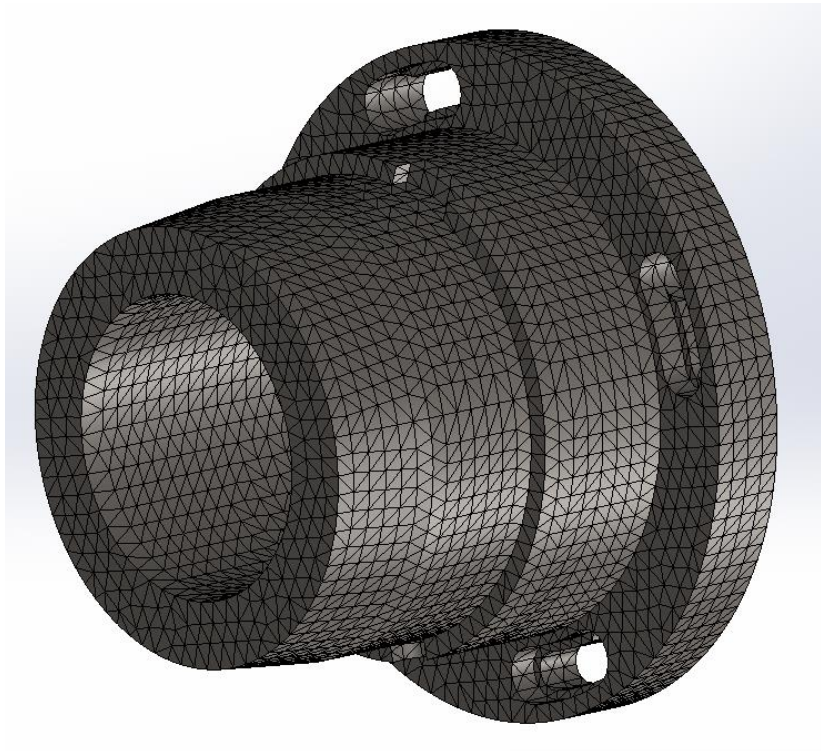

Figure 1: Initial mesh on the chuck used in the FEA

In order to improve the accuracy of the results it was decided that the use of an h-adaptive mesh would be ideal. This style of mesh uses the initial mesh but then refines it in multiple iterations in order achieve convergence of the results. Images of the convergence plots for both current and modified chucks can be found in Figure 2 and Figure 3 respectively.

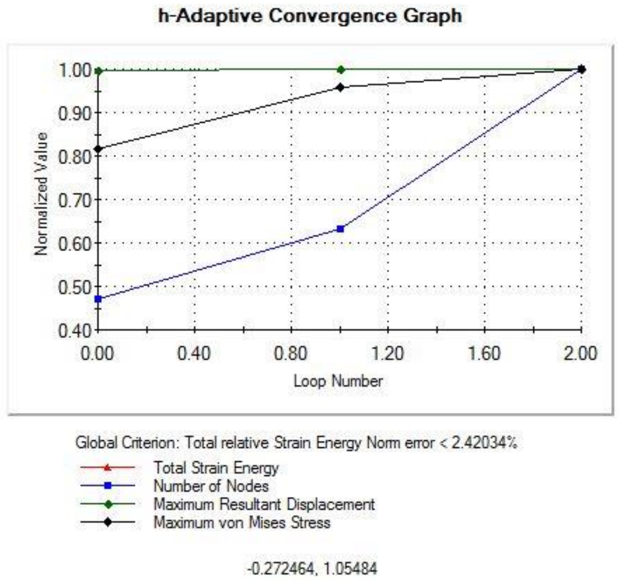

Figure 2: Convergence plot for the current chuck

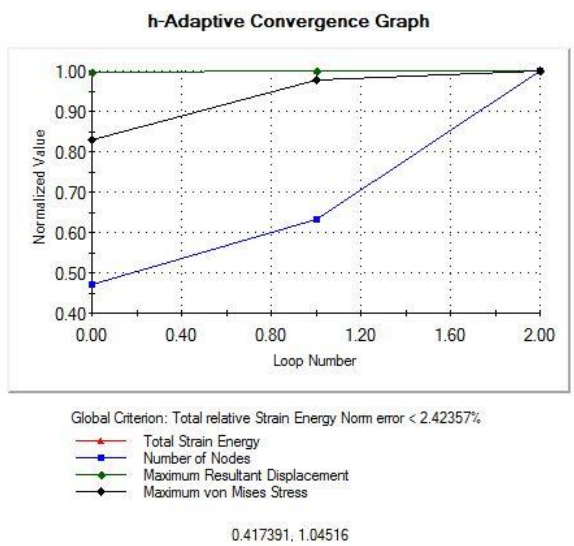

Figure 3: Convergence plot for the modified chuck

As is clear for the convergence plots our h-adaptive mesh achieved convergence. It is seen that as the number of nodes increases we get closer to the most accurate answer. Using this analysis we were able to generate vonMises stress contour plots. It can be seen in that the stress does not change significantly from the current chuck to the modified chuck. The max stress and the distribution of the stress stays relatively the same. This proves that the modification of the chuck does not significantly change the strength of the chuck. Therefore it is safe to move forward with the chuck modifications.

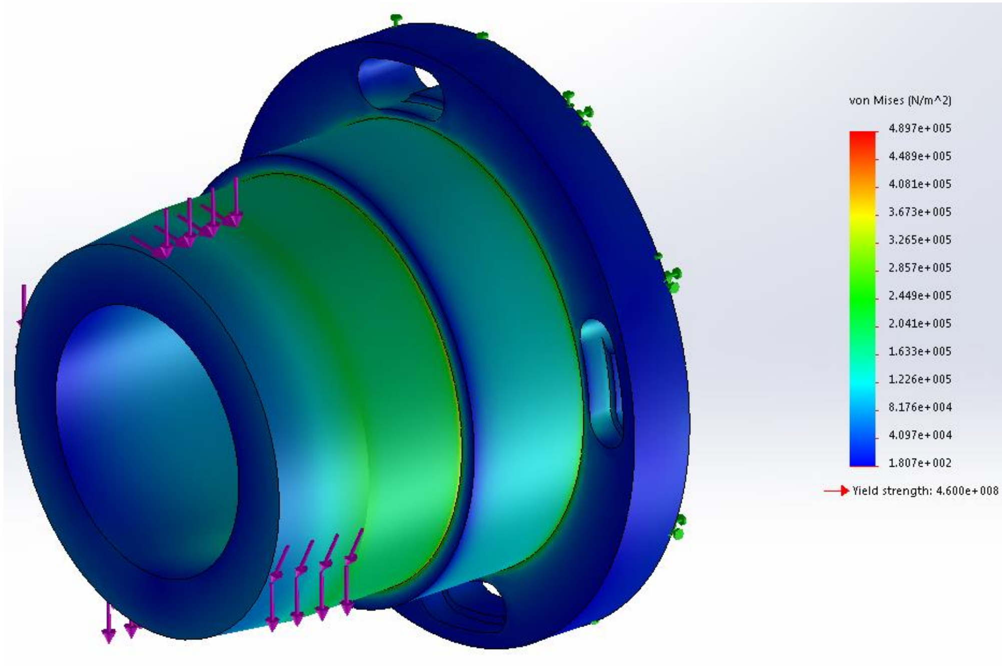

Figure 4: VonMises stress contour plot for the current chuck used by Winpak

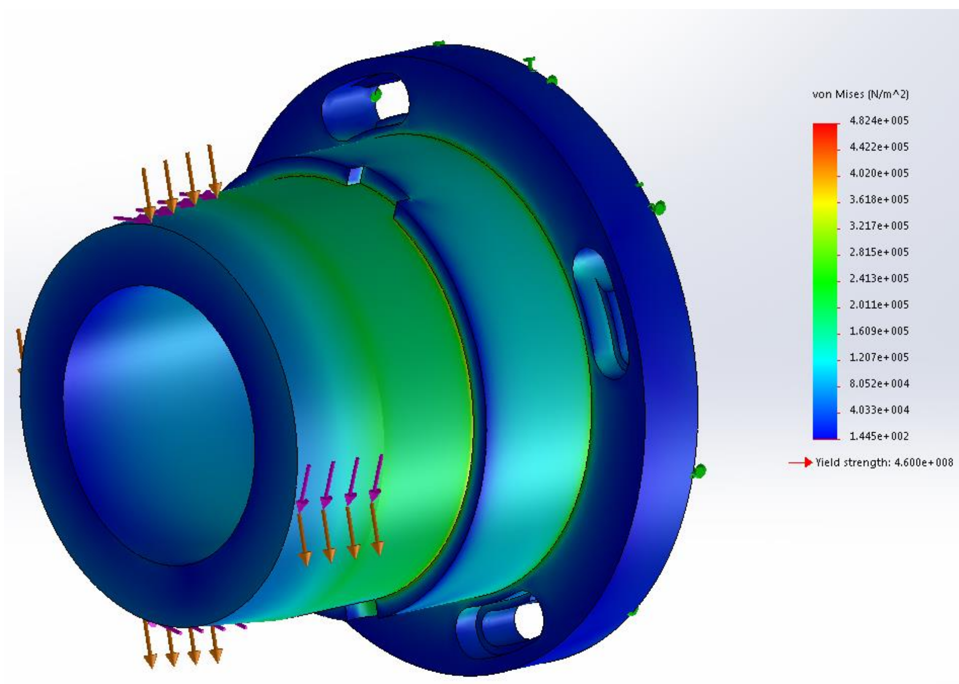

Figure 5: VonMises stress contour plot for the modified chuck proposed in this report

D.2 Engineering Drawings