DESIGN, CONSTRUCTION AND EVALUATION OF A COTTON MODULE TARP ROLLER

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ABSTRACT

This senior project addresses the design and construction of a modified cotton module tarp roller for Cross Creek Gin. The new cotton module tarp roller will be built with a gear reducer to ease the process of rolling the tarp. The purpose of this report is to create a tarp roller that will be easier for the operators to roll.

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INTRODUCTION

In cotton farming, when the cotton lint is harvested it is compressed into a module where they there are covered with tarps. The importance of the tarp is to keep the cotton from absorbing more moisture as well as keeping the cotton from getting contaminated with dirt or debris. These tarps are kept on the cotton modules from the time they are built, during transport to the gin where they are stored, until it is time for the tarp to come off right before the module starts its ginning process.

The Cross Creek Gin in Corcoran, CA uses a hand cranked cotton module tarp roller that was custom built by one of the shop employees of a neighboring farm that uses the gin. This cotton module tarp roller is used to get the tarps ready for transport to where the next modules will need to be covered or when they will be placed in storage. Currently, the hand cranked tarp roller takes physical strength and effort to roll the tarp up. It is also easy to bypass the steps that are needed to adequately roll the tarps for proper transportation and storage.

Figure 1. Cotton module tarp roller currently used and a rolled tarp

Another method available, which is used by a neighboring gin, is a tarp roller that uses an electric motor controlled by a foot operated switch. The electric motor makes it less physically straining for the employee. However the employees are bypassing certain safety precautions and getting hurt. Therefore, there is a need for a modified cotton module tarp roller that will be safe to use, not require an employee to physically strain themselves, and produce an adequately rolled tarp cover.

The goal for the new cotton module tarp roller will first be to reduce the force needed to roll up the tarp. This will be accomplished by adding a gear reducer. Also, the table will be made longer and slightly wider to achieve a better support for the tarp. To also help the person rolling the tarp, the table will be made slightly taller.

LITERATURE REVIEW

Cotton harvesting starts with clearing the acres to be planted by means of ripping the dirt and tearing out weeds. Once the soil is broken up and made into rows, the cotton seed is planted. Cotton seed is typically planted using machines that can plant up to 10 to 12 rows at a time. Approximately six weeks after the seed is planted, flower buds begin to show up on the cotton plant. Within three weeks the flower buds blossom and turn into yellow flowers and progressively turn pink and then red. After three days of blossoming the flower falls away and leaves a green pod called a cotton boll. It takes about ten weeks from when the flowers blossoms to when the boll matures and opens up to reveal the cotton. The cotton plant is defoliated, removing leaves by means of chemicals, once the cotton has pushed out and there are enough bolls to initiate a harvest. After the leaves fall away the cotton is ready for harvest when the moisture content is below 12%.

Figure 2. Cotton Picker during harvest.

As cotton is harvested, it is dumped into a module builder which compresses cotton into one big bale, called a module, which typically weighs around 24,000 pounds. The modules are then transported to a gin where they are processed to pure cotton and then either stored, exported, or sold. For the cotton to become pure it goes through a ginning process of a few phases. (Gilkey, 2013).

Figure 3. Cotton module building.

The cotton gin process begins once the moisture content is in the appropriate range, typically between six and eight percent. Once the optimum moisture content is reached the modules are moved from the module yard, where they are stored, to the conveyer belt where it starts its ginning process. As the module is fed into the gin there are cylinders with teeth on it that pull the module apart and send it to the next step of the ginning process.

Figure 4. Module being fed into gin.

As the cotton is picked apart, it is blown through vents by high volumes of air to reach each process. The cotton starts in the gin by going through a series of cleaner cylinders which is also equipped with a dryer to eliminate any unnecessary moisture. These cleaner cylinders are used to rid the cotton fibers of any trash or debris. The step following the cleaners is where the cotton fiber is separated from the seed. High volumes of air continually push the cotton through a space that is separated by an extremely hot and fast spinning spindle which has blades attached to it. This method pulls the cotton fiber from the seed, rather than ripping it, giving it a more pure value.

Figure 5. Cotton seed being separated from cotton fiber.

After the cotton fiber is separated from the seed it goes through one more cleaning process. This is the last process before the cotton is baled so it is important to rid the cotton of trash, debris, and leaves of any kind to achieve the purest form of cotton possible. When the last cleaning process is finished the cotton goes to the bale press where it is compressed multiple times to achieve the proper size bale. After the bale is constructed it is bound with baling wire and sealed in a protective covering before being sold or stored for export.

Figure 6. Cotton fiber being pressed into a bale.

The finished cotton comes out in 500 pound bales typically. To make the 500 pound bale it takes 1700 pounds of raw cotton. The 1700 pounds of raw cotton will produce about 850 pounds of cotton seed that will go through the "cracker" where it is cracked and sold to a dairy for the cattle. The cotton seed is cracked so that the cows can digest it since it is a good source of protein. Cotton seeds that are not sold to a dairy go to storage and can be used for planting next year. (Gilkey, 2013).

It is important before the cotton gets to the gin that it is properly constructed in the cotton module builder to prevent low lint values and increased ginning costs, especially if there is going to be a significant amount of rainfall (Hardin, Searcy, 2010). Some gins work with multiple farmers which means they are working with a large amount of cotton and therefore modules will be sitting in the yard until it is their turn to be ginned. This is why it is important to properly construct and cover the cotton modules.

Moisture level in cotton plays a big role in the entire cotton process, from harvesting to ginning. “Research has long shown that, in general, cotton should be harvested below 12% moisture, cleaned, and ginned between 6 to 8% moisture to preserve cotton-fiber quality during the ginning process.” (Armijo, Baker, Hughs, McAlister, 2004). These protocols are followed to ensure that the fiber quality will not degrade in the commodity of a finished cotton bale that is to be kept in storage. “The National Cotton Council recommends that the moisture content of U.S. cotton bales be kept at or below 7.5%” (Armijo, Baker, Hughs, McAlister, 2004).

In early cotton production, cotton harvesting required many laborers. However, with inventions of new harvesting equipment, the ability of on-board module building capabilities exists. These systems require less labor and less experienced module builders since the on-board module builder is controlled by sensors and software. “The autonomous system can construct quality modules and reduce labor requirements with only a small additional investment in equipment” (Hardin, Searcy, 2010).

“The US Cotton Industry wants to increase market share and value by supplying pure cotton” (Eiceman, Funk, 2008). The key to achieving pure cotton is keeping as many contaminants out as possible. New technologies will make the process of identifying and removing these contaminants by using Ion Mobility Spectrometry (IMS). “Commercial IMS analyzers equipped with membrane inlets sampled air displaced from heated flasks containing seed cotton and five common plastic contaminants; bale twine, new and weathered polypropylene tarp, polyethylene film and plastic film shopping bags” (Eiceman, Funk, 2008). This method is in the next step of developing systems for commercial cotton gins. Another way to avoid contamination is by using module tarp covers that are put on and removed by gin employees. Conventional farmers use covers of various materials, such as canvas, that resist water penetration. “Canvas was used to cover the earliest modules, and the importance of that protection was demonstrated by the development of a standard for cotton modules that included the performance and design of canvas covers” (ASAE, 1997).

On-board cotton module builders use a plastic tarp that costs about 35 dollars for each round module. That plastic tarp used for round bales cannot be reused. Most other cotton module tarps are reusable for 3-5 years depending on maintenance quality. Canvas tarp benefits: keep module dry and protected from dirt and dust. This is important because the modules can only be run through the gin at a certain moisture content. The importance of keeping dirt and dust out is to achieve the ultimate goal of having the cleanest, purest fiber.

PROCEDURES AND METHODS

DESIGN PROCEDURE

Solid Works was used throughout the design of the tarp roller table due to its versatility and capabilities.

Preliminary Procedures. Before the design of the table could commence, several things needed to be accomplished. The current tarp roller table was kept at Cross Creek Gin in Corcoran, CA. A trip was needed to take measurements of the current tarp roller and determine tarp characteristics which consisted of: total length, total width, diameter of tarp rolled up, and weight of tarp. These measurements were necessary for determining potential table designs. Measurements were taken with a measuring tape and scale. The table and tarp were also required for testing purposes and therefore were brought to the Cal Poly campus so that tests may be performed.

Testing Procedure. Tests were performed to determine force requirements, in pounds, for rolling the tarp on the tarp roller at various stages. The force was measured using an Analog Force gauge which determined the amount of force it took to pull the handle half of a full rotation.

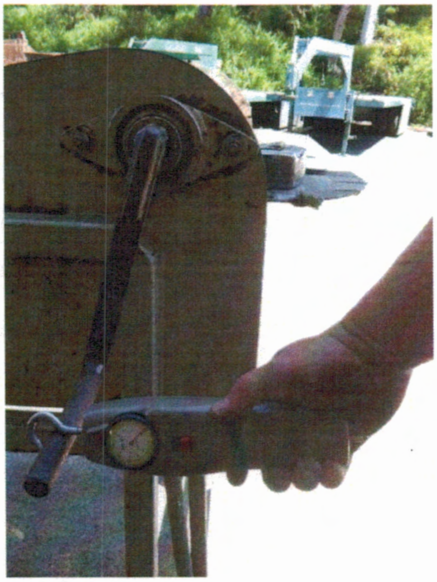

Figure 7. Analog Force Gauge used to measure torque.

The various stages tested were performed in five different intervals: the beginning of the roll, a quarter of the way through the roll, at half of the roll, three-quarters of the roll, and the end of the roll. These tests were taken twice on the roller, one with the tarp pulled over the heavy roller at the front of the table, referred to as "loose" in testing.

Figure 8. "Loose" testing position for tarp rolling.

The other test was performed with the tarp underneath the heavy roller at the front of the table, referred to as "tensioned" in testing.

Figure 9. "Tensioned" testing position for tarp rolling.

At each interval, after the amount of force was recorded to turn the roll half of a full rotation, the diameter of the roll was recorded for that specific interval as well. The last piece of information needed was the measurement of the handle radius. With all of the testing information, the data was organized into tables and graphs. Once the data tables were complete a new table was generated to present the amount of torque at each interval. The preliminary test results were used to design a new tarp table configuration.

Table Design. The manager at Cross Creek Gin was very specific that they did not want a motorized roller and their main concern was making it easier for the tarp to be rolled up properly. Since the characteristics of the table were acceptable to the employees, only minimal changes in the design were changed and only to benefit the ease of rolling the tarps even more. Therefore the measurements of the steel used were kept the same. The table was made slightly taller, longer, and wider to potentially reduce added force due to friction. Measurements of the table are 48 inches tall, 56 inches long, and 32 inches wide. The frame for the table was made with 1.5 x 1.5 inch steel tubing with a wall thickness of 3/16 inch. For the deck of the table, .093 inch thick sheet metal was used. The deck will be rolled to achieve a better support for the tarp to follow while being rolled up from the ground.

Figure 10. Table design.

Also a gear reducer of three to one was put in place. The gear reduction will be achieved with a sprocket and chain assembly. To get the three to one ratio a driver sprocket with fifteen teeth was used and a driven sprocket with forty-five teeth was used. These sprockets were chosen with pitch number of sixty, therefore a pitch sixty single strand chain will be used to link the two sprockets together. Size sixty pitch was chosen for this design because the sponsor did not want to have small moving parts, like size thirty-five or forty pitch. Since size sixty pitch was chosen there was a limited selection of sprockets from McMaster-Carr. This is why sprockets of forty-five and fifteen teeth were chosen, it was the smallest size available to achieve the three to one ratio. Sixty pitch chain also has a working load of over one thousand pounds which is adequately strong. The driven sprocket will be attached to the bearing that the mandrel slides in and out of to remove tarps. The driver sprocket will be assembled with a flange bearing attached to the side wall of the table and supported by a mounted bearing. This assembly will be supported with a bracket constructed with angle iron, flat bar, and steel tubing for gussets.

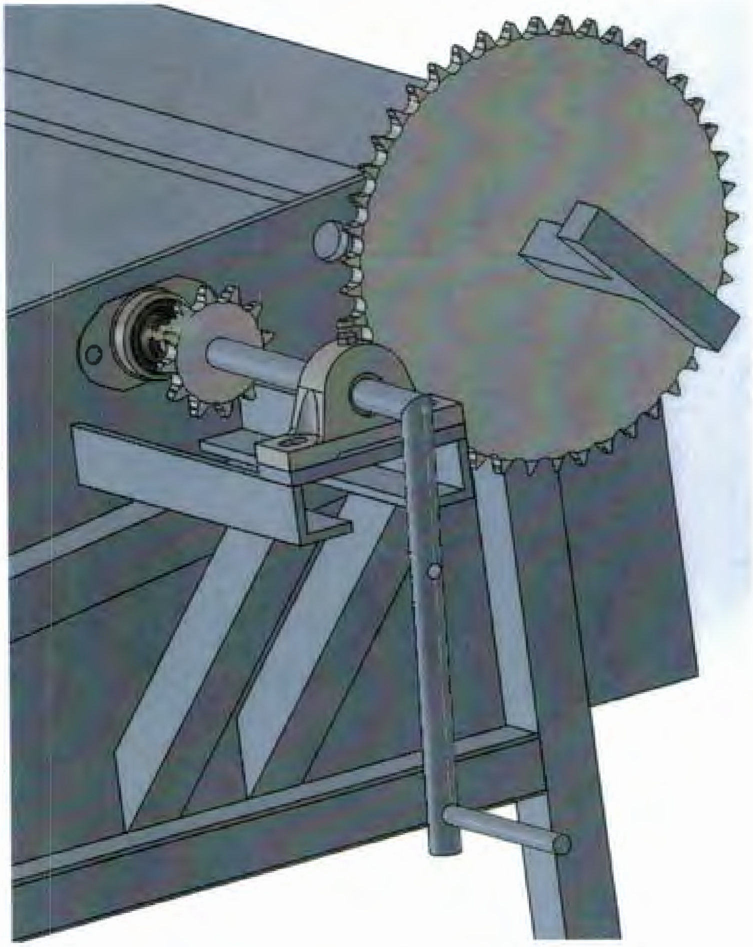

Figure 11. Gear reduction assembly.

The last part of the design was the crank that will be attached to the driver part of the assembly. To make it easier for the tarp roller operator, besides the gear reduction, the crank will have slots in it at two different crank radiuses. The slots purpose is so the crank handle can be adjusted by simply pulling the handle out from one slot and placing it in the next. This will allow the operator to make small and effortless motions for when the tarp is easiest to roll. Then when it becomes difficult to roll the tarp the operator will pull the handle out of its slot and place it in the longer distance slot to create more torque which will make it easier to roll the tarp at its difficult stages. The removable handle will be attached by nut and bolt. Overall the new design's goal was to reduce the amount of human force that is required to roll the tarp.

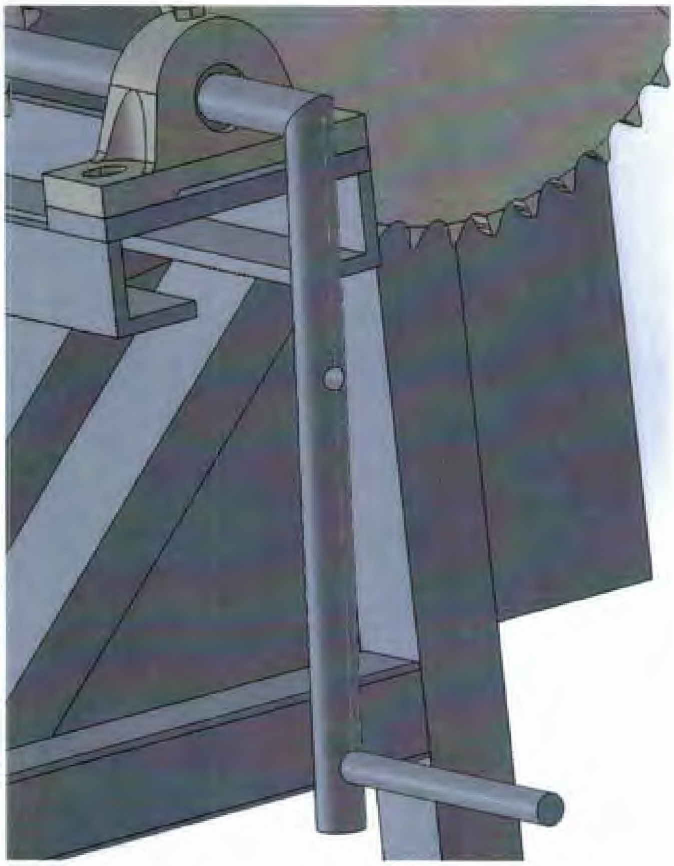

Figure 12. Crank handle assembly.

FABRICATION PROCEDURE

All of the fabrication was done with the equipment in BRAE Shops 6 and 7. The fabrication process started with the machinable 60 pitch driven sprocket ordered from McMaster-Carr which had: 45 teeth, an outside diameter of 11.18 inches, width of .46 inches, and minimum bore diameter of 15/16 inch that was machinable up to 9.276 inch maximum bore diameter. The machinable sprocket was selected in order to mill out a square bore so that square mandrel could slide through it as well as the bearings attached to the table.

To achieve the square bore the driven sprocket was secured to the Victor DRO Mill. Before completely securing the sprocket it was aligned to center by placing a 15/16 inch drill bit through the manufactured 15/16 inch bore. The DRO (digital readout) was turned on and zeroed out. Once the sprocket was centered a 1 inch drill bit was used to remove the majority of the material needed to create a 1 inch square bore. The drill bit moved .200 inches in the y direction. The computer that read the axis measurements was zeroed out once more to ensure the center point. An edge cutter with a diameter of .285 inches was selected to carefully mill the square bore out of the sprocket. Since the drill was centered and the square bore was to be 1 inch, half of the edge cutter diameter was taken, .1425 inches, and subtracted from 1/2 inch, which equaled .3575 inches. .3575 inches was the distance to be traveled in the x and y direction both positive and negative from the center point. By reeling the table in a clockwise square direction, this would produce the desired 1 inch square bore. (See Appendix B for diagram). The edge cutter was only capable of taking approximately .020 inches of material off at a time. Therefore the rotation needed to be done approximately 23 times.

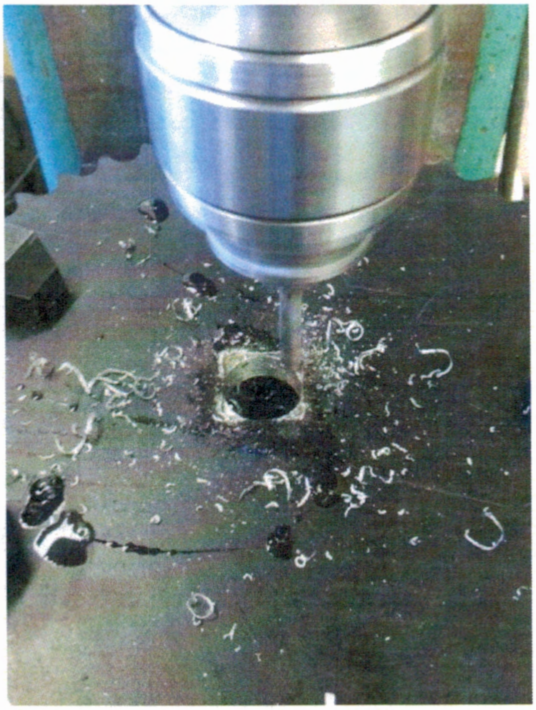

Figure 13. Milling square bore on driven sprocket.

The next step in the fabrication procedure was to assemble the bearings for the driver sprocket. To line the sprockets up, 2 1/2 inches were measured from the wall of the table to the face of each sprocket. A distance of 18 1/2 inches was measured from the center of each sprocket to create a comfortable distance between each sprocket as well as providing the chain with an easy path to rotate. Once the center of the driver sprocket was determined, the flange bearing was lined up, and holes were drilled through the table to bolt the flange bearing to the table. Slightly bigger holes were drilled to allow the flange to slide from side to side for chain tensioning. The mounted bearing was placed 4 1/2 inches from the wall of the table. To support the mounted bearing 1.5 by 1.5 inch steel square tube was cut at 45 degree angles and used as gussets. A 3/8 by 1.5 inch flat bar was welded to top of the gussets as a level surface for the bearing to mount to. Before the flat bar was mounted to the gussets oversized holes were drilled to act as slots to allow for chain tensioning with respect to the flange bearing. Holes were also cut in the square tubing so that a wrench could be used to tighten the bearing to the flat bar.

Figure 14. Driver sprocket assembly.

The crank handle was measured to come out 7 1/2 inches from the wall of the table giving a comfortable turning space. To make the crank handle, 3/4 inch round stock was cut at 45 degrees at 7 1/2 inches and 11 inches. Quarter inch holes were drilled 4 inches and 10 inches on the 11 inch part of the handle. These holes were drilled to allow for the capability of changing your handle radius. Changing the handle radius gives the operator the option to use a short handle radius when the tarp takes minimal force to crank and a longer handle radius for when the tarp requires more force to crank. The driver sprocket was welded to the crank handle so its face was 2 1/2 inches from the wall. To line the driven sprocket with the driver sprocket a 1 5/8 inch inner diameter steel pipe was cut at 1 inch to act as a spacer. The spacer was welded to the driven sprocket as well as the bearing. This way with the driven sprocket welded to the bearing the mandrel could slide in and out of the sprocket and bearing, while the sprocket stayed in place, so the tarp may still be removed. Once the gear reduction system was assembled the chain was measured, put on, and then tensioned by sliding the bearings back and tightening them down.

Figure 15. Complete gear reduction assembly.

Quarter inch diameter bolts were used for the adjustable handle here for testing purposes.

RESULTS

PRELIMINARY TESTING

The original tarp test results show the relationship between the amount of force it took to roll the tarp and approximately how much, roll diameter, of the tarp was rolled. This test was performed twice to account for the tarp going over the heavy roller, referred to as slop, and the tarp going under the heavy roller, referred to as proper. The tarp was measured in five different positions: the start of the roll, quarter of the roll, half of the roll, three quarters of the roll, and the end of the roll. Diameter of the tarp was measured in each position.

Table 1. Results of tarp roller without gear reduction.

Loose		**Amount Rolled**		**Tensioned**
Force(#)	Diameter(in.)		Force(#)	Diameter(in.)
12	5	**Start**	10	4
20	6.5	**Quarter**	16	5.75
31	8.25	**Half**	23	7.5
39	10	**Three-Quarters**	25.5	9
43	11.25	**End**	41	11

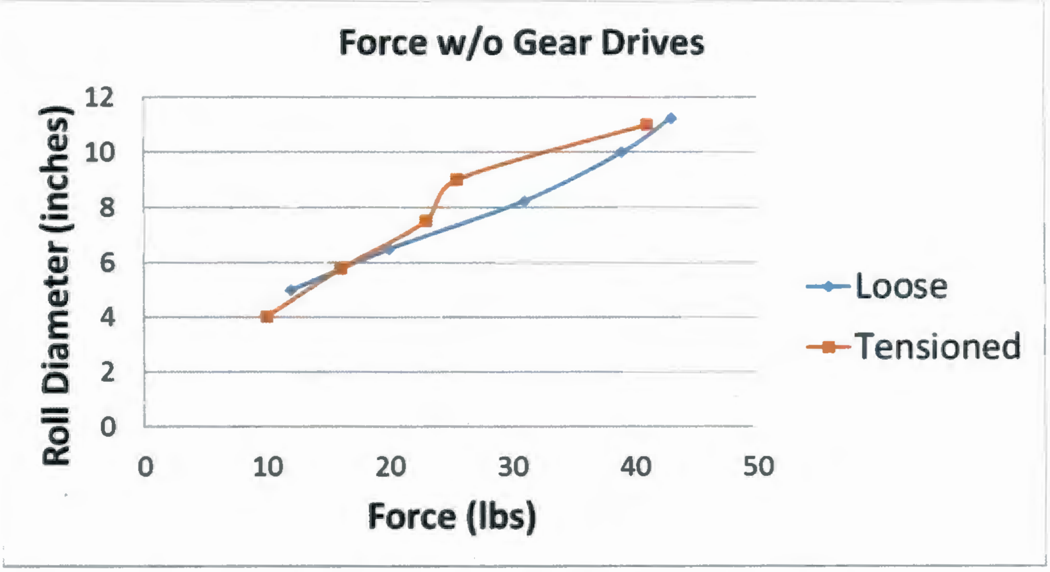

Figure 16. Relationship of force and roll diameter.

GEAR REDUCTION RESULTS

Once the gear reduction system was assembled the same tests were performed in the same environment with the same tools. The test was first performed with the 4 inch handle radius.

Table 2. Gear reduction with 4 inch handle radius.

Loose		**Amount Rolled**		**Tensioned**
Force(#)	Diameter(in.)		Force(#)	Diameter(in.)
2	4	**Start**	8	3.5
12	5.25	**Quarter**	17.5	6
22	8	**Half**	21	7.5
24	9.5	**Three-Quarters**	29	9
34	11	**End**	35	11

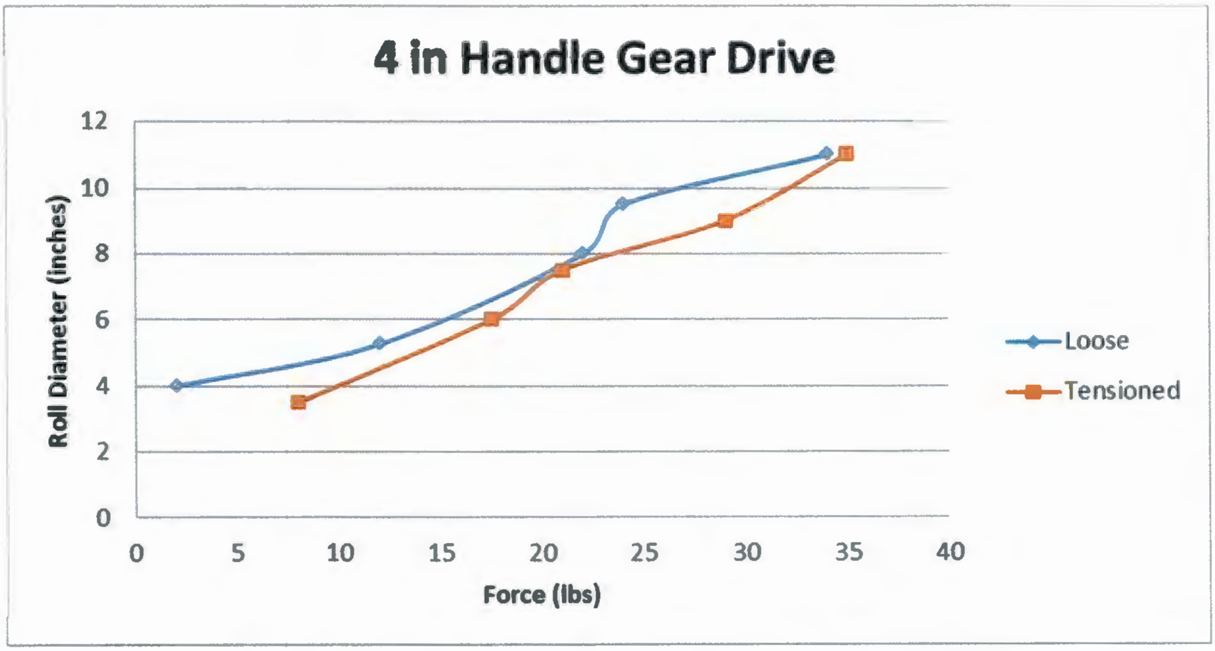

Figure 17. Relationship of force and roll diameter.

The test was performed once more to observe the results of the 10 inch handle radius.

Table 3. Gear reduction with 10 inch handle radius.

Loose		**Amount Rolled**		**Tensioned**
Force(#)	Diameter(in.)		Force(#)	Diameter(in.)
2.5	4	**Start**	4	3.5
3	5.25	**Quarter**	7	6
6.5	8	**Half**	9	7.5
8	9.25	**Three-Quarters**	12	9
13	11	**End**	13.5	11

Figure 18. Relationship of force and roll diameter.

To determine the efficiency of the gear reduction as well as the adjustable handle radius, the two different handle radiuses were compared when rolling the tarp in the slop position and the proper position.

Figure 19. Comparison of 10 inch handle vs 4 inch handle in Slop position.

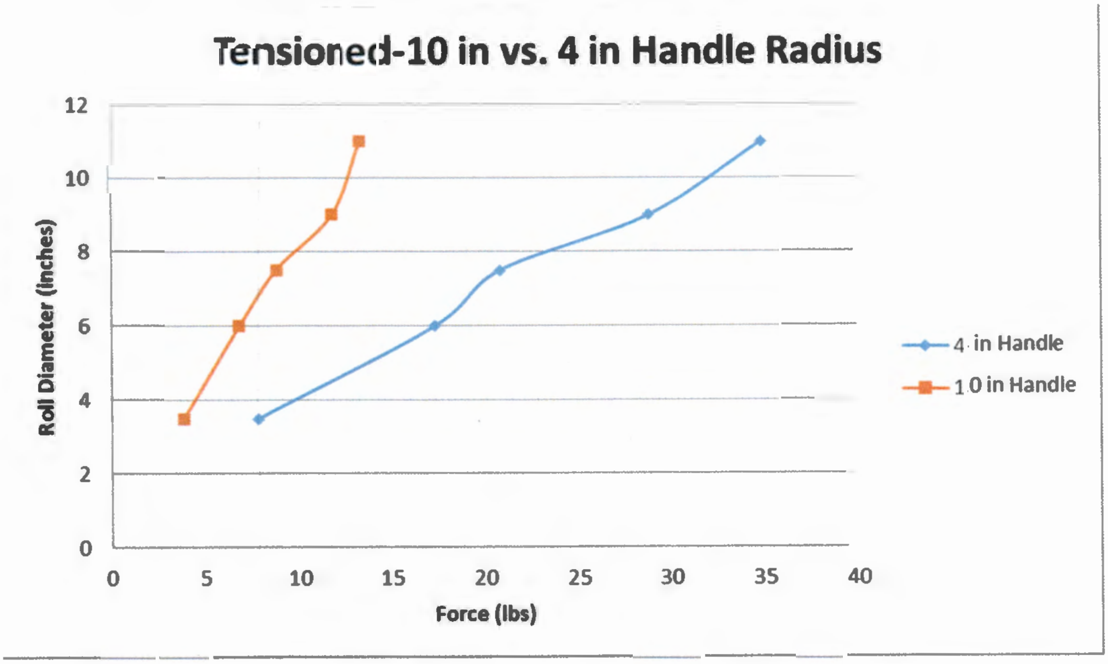

Figure 20. Comparison of 10 inch handle vs 4 inch handle in Proper position.

DISCUSSION

FABRICATION ANALYSIS

During the fabrication process the most difficult part was welding the pipe used as a 1 inch spacer between the driven sprocket and bearing. It was most likely difficult due to the fact that the thickness of the bearing and sprocket were much thicker than the pipe and it was going to take more heat to penetrate and bind to each of them. Part of not getting enough heat to the sprocket and bearing could have been related to the gap being too tight of a spot to get the tip of the welder close enough. Another fabrication concern was making sure the sprocket and chain assembly had enough clearance so the chain would not rub against the driver sprocket support assembly. This issue corrected itself when the chain was tensioned.

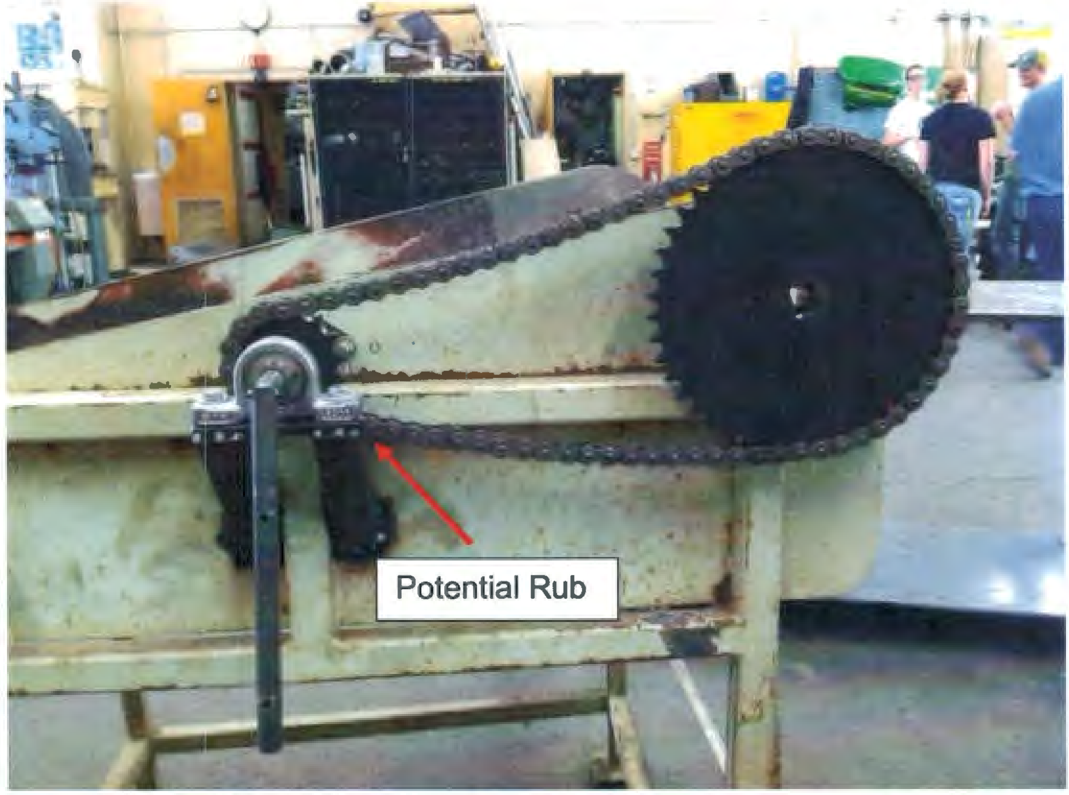

Figure 21. Potential location of interference.

RESULTS ANALYSIS

Overall the purpose of the design was to reduce the amount of force it takes to roll up the tarp. In the original test results graph, on the tensioned line, there is a bump between the force it took to roll the tarp half way and three quarters which occurred due to an overlap of the roll.

SAFETY ANALYSIS

When the gear reduction assembly was added to the table it created several new pinch points that could potentially be a safety hazard. To prevent injury a safety guard should cover any potential areas prone to pinch hazards. A safety guard will be installed before being sent back to the cotton gin.

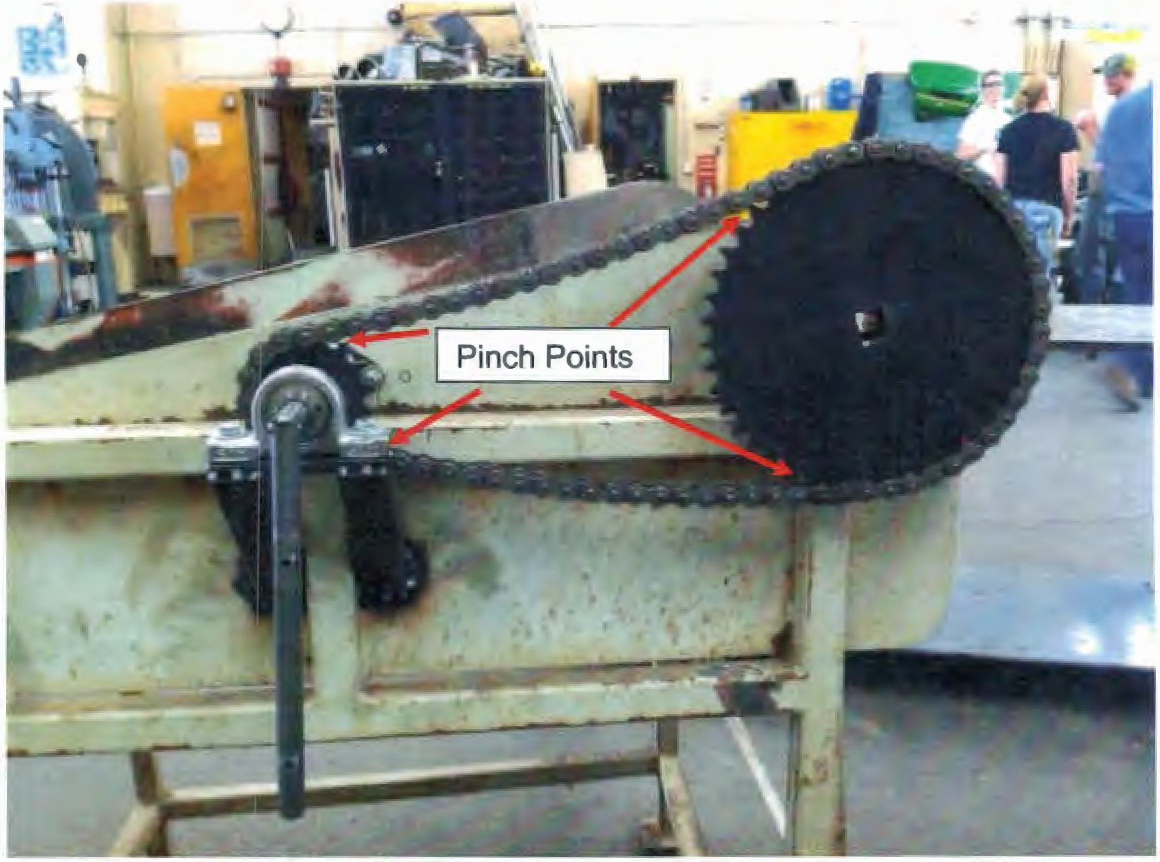

Figure 22. Potential pinch points.

COST ANALYSIS

Table 4. Bill of Materials for Gear Reduction Assembly.

Gear Reduction Assembly					
Bill of Materials					
Part	Description	**Quantity**	**Size**	**Price**	**Source**
2299K66	Machinable-Bore Sprocket	1	3/4" Pitch, 15 Teeth	$ 28.17	McMaster-Carr
2299K82	Machinable-Bore Sprocket	1	3/4" Pitch, 45 Teeth	$ 67.11	McMaster-Carr
6261K176	Single Strand Roller Chain	1	#60, 5 Feet	$ 30.25	McMaster-Carr
7208K54	Steel Flange Mount Bearing	1	3/4" Shaft	$ 34.15	McMaster-Carr
6494K13	Cast Mounted Steel Bearing	1	3/4" Shaft	$ 34.74	McMaster-Carr
	Round Stock	1	3/4"x48"	$ 7.56	Sawtelle & Rosprim
	Square Tubing	1	1 1/2x1 1/2x.250" HST 48"lg	$ 14.00	Sawtelle & Rosprim
	Flat Bar	1	3/8x1 1/2x24"	$ 2.72	Sawtelle & Rosprim
	Miscellaneous Hardware			$ 5.00	Sawtelle & Rosprim
		Merchandise Total =		**$223.70**	

Table 5. Cost of Labor estimated at $60 per hour.

Cost of Labor		
Estimate Labor Wage of $60 per hour		
Task	**Time (hours)**	**Cost of Labor**
Milling	3	$ 180.00
Cutting	2	$ 120.00
Drilling	2	$ 120.00
Layout	1.5	$ 90.00
Welding	1	$ 60.00
Assembly	3	$ 180.00
Totals	**12.5**	**$ 750.00**

The total cost to add the gear reducer to the tarp roller would be $973.70

RECOMMENDATIONS

To make this tarp roller easier for the operator to roll up I would consider putting some type of surface on the table that would create less friction. Even though sheet metal does not create an extreme amount of friction between it and the tarp, a sheet of UHMW would make a nice surface for the tarp to roll up on.

A roller or spool in between the two sprockets that travels on a vertical slot would make an easier chain tensioning device.

One main concern would be removing the mandrel with the tarp rolled all the way up. This new gear reduction is creating such a tight roll, which was one of the goals; it becomes difficult to remove the mandrel. Since the mandrel is made of bar stock, some sort of material, such as UHMW, could be mounted to reduce the friction and make it easier to pull the mandrel out. The other option is removing the square mandrel and replacing it with a round one.

There are limited options here due to the fact that the purpose of the tarp roller was to not create more work for the employees and to keep the tarp roller simple.

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APPENDICES

APPENDIX A:

HOW PROJECT MEETS REQUIREMENTS FOR THE ASM MAJOR

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ASM Project Requirements

The ASM senior project must include a problem solving experience that incorporates the application of technology and the organizational skills of business and management, and quantitative, analytical problem solving. This project addresses these issues as follows.

Application of Agricultural Technology. The project will involve the application of mechanical systems and fabrication technologies.

Application of Business and/or Management Skills. The project will involve business/management skills in the areas of machinery/equipment management, cost and productivity analyses, and labor considerations.

Quantitative, Analytical Problem Solving. Quantitative problem solving will include the cost analysis and the capability of reusing the tarp roller on independent tarps.

Capstone Project Experience

The ASM senior project must incorporate knowledge and skills acquired in earlier coursework. This project incorporates knowledge and skill from these key courses:

- BRAE 129 Lab Skills/Safety
- BRAE 133 Engineering Graphics
- BRAE 142 Machinery Management
- BRAE 152 3D Solids Modeling
- BRAE 203 Agricultural Systems Analysis
- BRAE 301 Hydraulic and Mechanical Power Systems
- BRAE 321 Ag Safety
- BRAE 342 Ag Materials
- BRAE 343 Mechanical Systems Analysis
- BRAE 344 Fabrication Systems
- BRAE 418 Ag Systems Management I
- BRAE 419 Ag Systems Management II

ASM Approach

Agricultural Systems Management involves the development of solutions to technological, business and management problems associated with agricultural or related industries. A systems approach, interdisciplinary experience, and agricultural training in specialized areas are common features of this type of problem solving. This project addresses these issues as follows.

Systems Approach. The project involves the integration of multiple functions (transporting, mechanical system, and safety guards), and the integration of machine/operator/reuse to provide an improved time management process as well as contamination prevention.

Interdisciplinary Features. The project touches on aspects of mechanical systems, agricultural safety, time and cost management.

Specialized Agricultural Knowledge. The project applies specialized knowledge in the areas of mechanical and fabrication systems, and agricultural safety.

APPENDIX B:
SQUARE BORE DIAGRAM

SQUARE BORE DIAGRAM

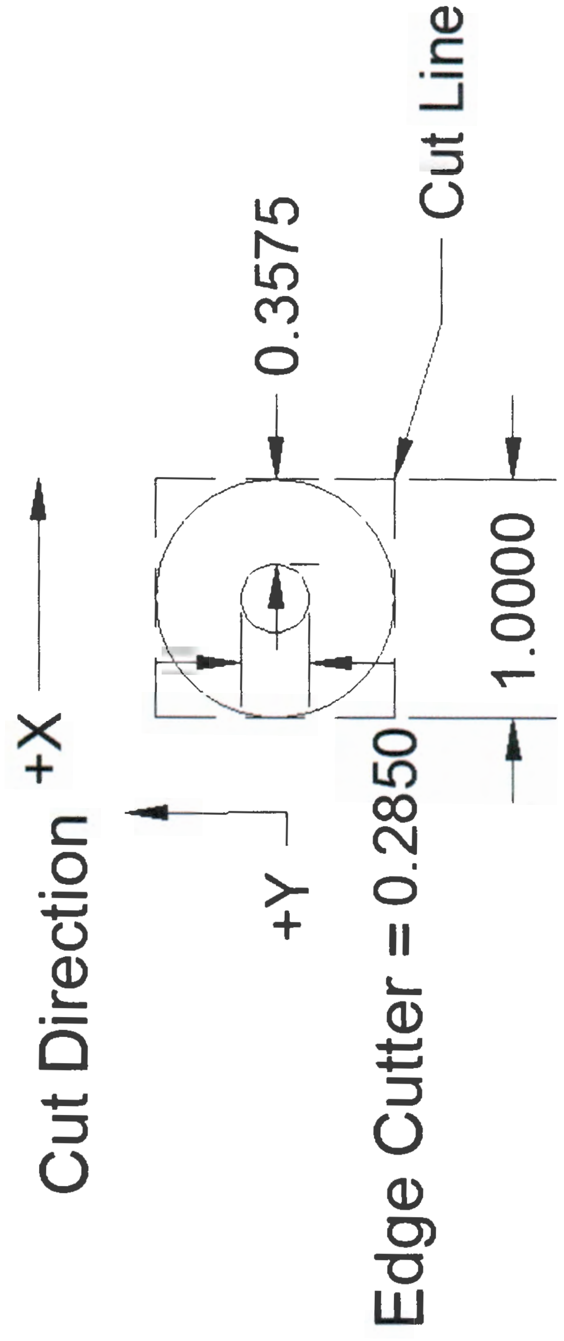

Figure 23. Square Bore Diagram.

APPENDIX C:
CONSTRUCTION DRAWINGS

CONSTRUCTION DRAWINGS

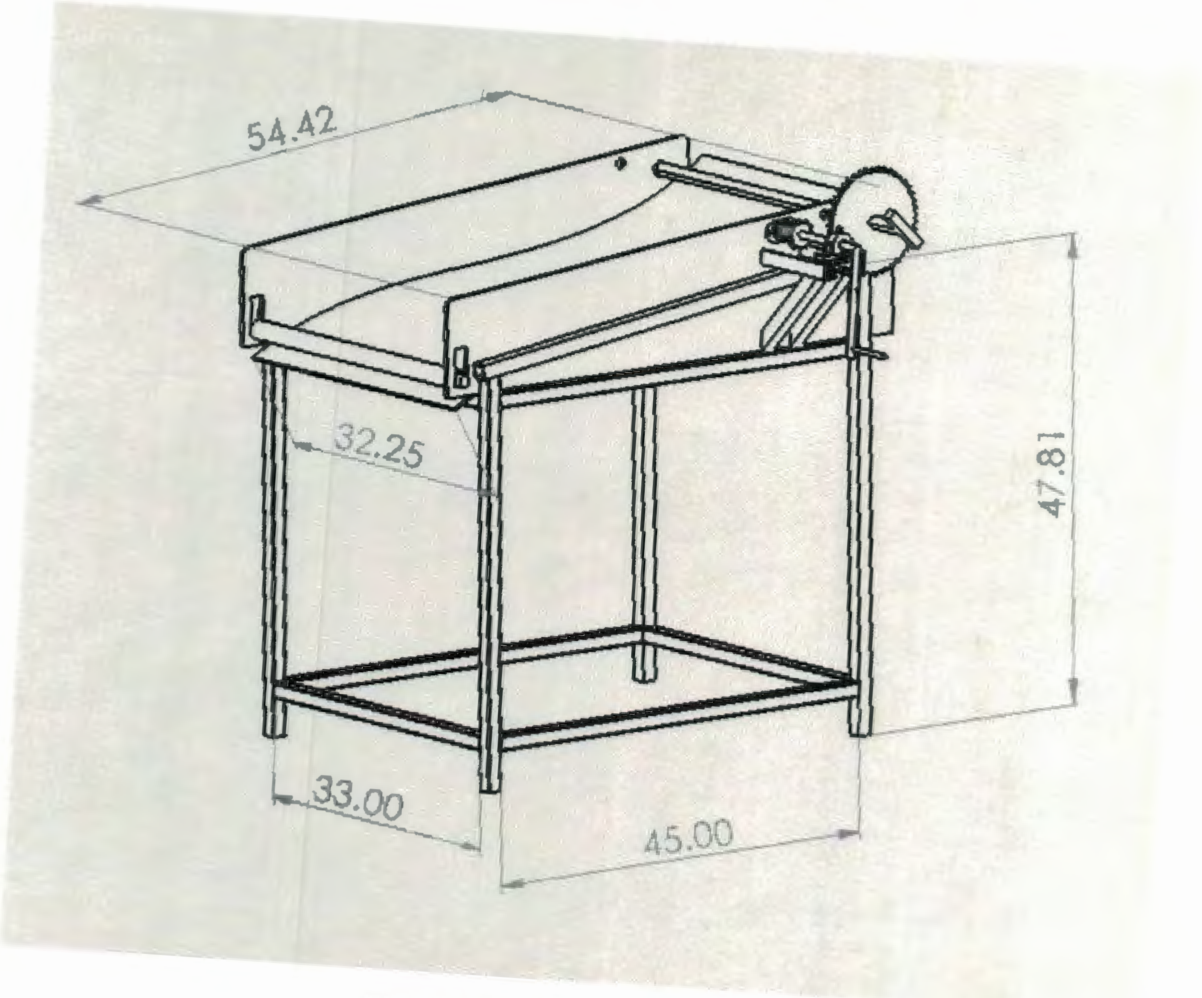

Figure 24. Table Dimensions.

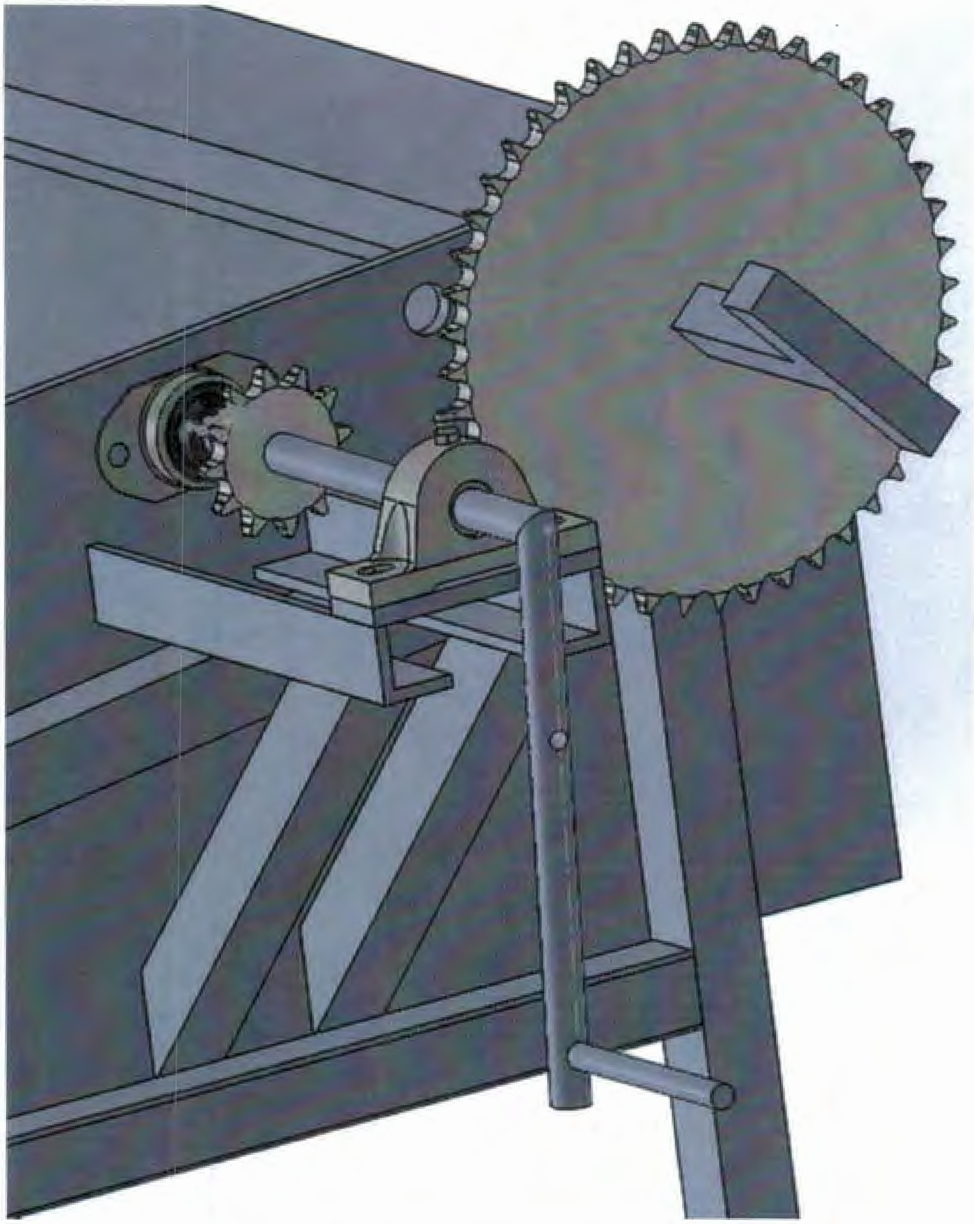

Figure 25. Gear Reduction Assembly.

APPENDIX D:
FORCE VS TORQUE TABLES

FORCE VS TORQUE TABLES

Original Tarp Roller				
Loose		**Amount Rolled**		**Tensioned**
Force(#)	Diameter(in.)		Force(#)	Diameter(in.)
12	5	**Start**	10	4
20	6.5	**Quarter**	16	5.75
31	8.25	**Half**	23	7.5
39	10	**Three-Quarters**	25.5	9
43	11.25	**End**	41	11

Table 6. Original tarp roller test results.

With Gear Reduction				
4 inch handle radius				
Loose		**Amount Rolled**		**Tensioned**
Force(#)	Diameter(in.)		Force(#)	Diameter(in.)
2	4	**Start**	8	3.5
12	5.25	**Quarter**	17.5	6
22	8	**Half**	21	7.5
24	9.5	**Three-Quarters**	29	9
34	11	**End**	35	11

Table 7. 4 inch handle with gear reduction results.

With Gear Reduction 10 inch handle radius				
Loose		**Amount Rolled**		**Tensioned**
Force(#)	Diameter(in.)		Force(#)	Diameter(in.)
2.5	4	**Start**	4	3.5
3	5.25	**Quarter**	7	6
6.5	8	**Half**	9	7.5
8	9.25	**Three-Quarters**	12	9
13	11	**End**	13.5	11

Table 8. 10 inch handle with gear reduction test results.