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Alternative String-Trimmer Starting Device

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TRINITY UNIVERSITY

ENGR-4381

Final Design Report

Alternative String-Trimmer Starting Device

Jacob Campbell, Jeremy Lavorin, Tasha Lovell, Joseph Marina, Paurakh Rajbhandary, and Cole Wollak

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4/25/2011

A mechanical string trimmer starter is designed in collaboration with Goodwill Industries of San Antonio, so that the Goodwill can employ people with limited hand-arm dexterity who would otherwise be turned away from a string trimming (landscaping) job. The power spring based mechanical string trimmer starter design includes a 6.58" x 7.08" x 7.92" aluminum box that is attachable to the rear surface of the string trimmer via a custom made aluminum attachment. The design comprises of three subsystems – the energy input, energy storage, and the energy release subsystems. The device allows the operator to compress a plunger (rack) repeatedly to store the energy in a power spring and release the accumulated energy using a ratchet mechanism. The overall design, weighing 16 lb_m, requires 30-40 complete plunge compression cycles, with the force required to press the rack increasing successively as the spring charges. The maximum force of 30 lb_f is required to push the plunger during the final plunge cycle. The design provides a torque of over 100 in-lb_f and angular frequency of 3 total turns to the engine's crankshaft, sufficient to start a cold engine based on the tests performed on the Shindaiwa T272 trimmer.

Executive Summary

The project to create a power spring based string trimmer starter design is a two semester senior design project at the Engineering Science Department, Trinity University. A group of six students and a faculty advisor work in collaboration with Goodwill Industries of San Antonio, a non-profit agency (NPA), to create a mechanical starter for the Shindaiwa T272 model string trimmer. The design can be adopted for other brands of string trimmers by using appropriate gears and power springs required for the particular model.

The design capable of starting a Shindaiwa T272 string trimmer should supply a torque, angular velocity and turn of 54.9 in-lb_f, 800 RPM, and 4.5 angular turns to the engine's crankshaft. The criteria for the torque and angular velocity are obtained from the tests, shown in Appendix A, performed on the Shindaiwa string trimmer using a watt meter and infra-red tachometer. The criterion for the number of angular revolutions is determined by observing that the cord pull mechanism turns the crank-shaft through 4.5 revolutions when the cord is fully extended, however further testing showed that 3.5 revolutions could successfully start the engine. The starter device is constrained by weight, size, force, and dexterity required to start the string-trimmer. The development and production cost also constrain the design monetarily. The constraints are determined based on decisions made by project members, and feedback provided by Goodwill Industries of San Antonio. Based on this information and the 14.7 lb_m dry weight of the Shindaiwa T272, the weight constraint of the device is determined to be so as not to offset the center of gravity of the string trimmer (shown in Appendix I), rather than an exact numerical value. The center of gravity relationship can also be seen in Eq. 2 of Appendix I. The development cost of the design is constrained by the $1200 fund that is provided by the Trinity University Engineering Science Department. The production cost of the starter should be proportionally less expensive than the price of the string trimmer.

The power spring starter design is enclosed in a 6.58" x 7.08" x 7.92" box that is attachable to the rear surface of the string trimmer (illustrated in Fig. 9). The three subsystems – the energy input, energy storage, and the energy release subsystems (see Fig. 2) — allows operator to charge the spring with repeated plunges and release the power spring once it is fully charged. At first, the operator pushes the plunger down so that the gear and the axle rotate. Then, the restoring extension spring pulls the plunger back to the original position. However, during the restoring stage, the axle does not rotate because of a free wheel mechanism installed between the gear and the gear axle. In essence, with each plunge depression, the axle rotates in one direction. The gear axle is attached to the power spring axle via an auto-disconnect clutch. An auto-disconnect clutch is specifically used in application such as for winding the power spring. As the gear axle rotates, the clutch engages the two axles, which results in the winding of the power spring. A ratchet mechanism that is placed in the spring axle ensures that the spring's restoring force does not drive the axle in the opposite direction. Once the spring is fully charged, the operator can disengage the ratchet to allow the spring to release. During this time, the auto-disconnect clutch disengages the gear axle from the spring axle. The potential energy stored in the spring is delivered to the string trimmer's crankshaft. The axle and the crankshaft are connected via an aluminum adapter.

The design, weighing 16 lb_m, requires at maximum 33 complete plunge compression cycles, with increasing force required to press the plunger with each successive plunge. The device applies a torque of more than 100 in-lb_f and an angular turn of 3 cycles to the engine's crankshaft, sufficient to start a relatively cold string trimmer, based on the tests performed on the Shindaiwa T272

trimmer. Once a complete prototype of the device was constructed, it was subjected to an optimization test where multiple parts failed due to stress. Thus, final testing was not concluded.

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1 Introduction

According to a report released by the U.S. Department of Labor, Bureau of Labor Statistics, about 1.5 million people occupied grounds maintenance jobs in 2008, and the projected growth of employment in this field for 2008-2018 is 18%, a growth rate higher than national average for all occupations [1]. With so many stakeholders invested in grounds maintenance, ease of operation must be a significant component of landscaping tool design. If employees in the landscaping profession cannot carry out their job responsibilities, work productivity in using landscaping equipment will fail to reach its full potential. Specifically, the standard starting mechanism for string-trimmers is not particularly easy to use. Traditional string-trimmers require that the user forcefully pull a recoil cord to rotate the engine and begin the combustion cycle. This motion requires much physical strength and dexterity, which can be difficult for those who lack in arm strength or have a disability. This problem excludes people with low arm strength or a disability from grounds maintenance jobs.

Employers are prohibited from excluding those with disabilities from available positions if reasonable accommodations can be made, as stated by the Americans with Disabilities Act (ADA) of 1990 [2]. Goodwill Industries accommodates a vast number of people with disabilities. In fact, Goodwill employs a workforce for which over 75% claim a disability [3]. But many workers are turned away from certain grounds maintenance positions because of the arm strength necessary to start a string-trimmer. They are also rejected because there is currently no straightforward method to accommodate workers with disabilities into such positions. A starting mechanism that reduces the amount of arm strength required by the operator would allow Goodwill Industries to employ persons with disabilities.

The objective of the String Trimmer Starter Senior Engineering Design project is to design a portable starting mechanism for an internal-combustion-engine-based string trimmer that reduces the amount of arm strength required by the operator. The design should facilitate convenient startup of string trimmer regardless of location (shop or in the field) and should not be limited to the availability of fixed power source. Specifically, the starter design should rotate the crank-shaft by at least 3.5 cycles, while providing a torque of 100 lb_f-in, and an angular velocity of 800 RPM. These criteria are based on preliminary tests performed on the Shindaiwa brand string trimmer to determine the minimum values of each parameter required to start the string trimmer.

The torque, however, was calculated in house using a digital tachometer and a watt-meter to measure power. The data for the three run test that was conducted can be found in Appendix A. The derivation of design criteria are shown in the Appendix C and D.

The design is constrained by the size, weight, development and manufacture costs. The force and dexterity required to operate the starting mechanism also constrain the design as they should be minimized. The size of the mechanism should not be large in proportion to the size of the string trimmer engine. Thus, it was determined that the width, length, and height of the starting device should not exceed 10x10x7 in. The weight of the design is constrained by the center of gravity relationship given in Eq.1 of Appendix I. The development cost for the design is limited to the $1200 funding provided by the Department of Engineering Science, Trinity University. The manufacturing cost of the design should be no greater than $100. Finally, dexterity required to operate the alternative starting mechanism should be minimized.

2 Design Overview

The power spring starter outputs a certain torque (τ) and an angular revolution (Θ) based on the maximum force (F_{max}) and the number of plunges (N) used to charge the power spring, as shown in Fig. 1. Maximum force (F_{max}) is taken as the standard force parameter because the force required to push the plunger gets successively higher as the spring charges. A tradeoff relation exists between the required maximum force and the number of plunges. If a smaller gear is used, less plunger compressions would be required; however, the maximum force required would increase. The design allows the operator to push down on the plunger using their hand or foot. Using the foot allows force to be delivered more easily compared to using the upper body, which requires high arm and shoulder strength.

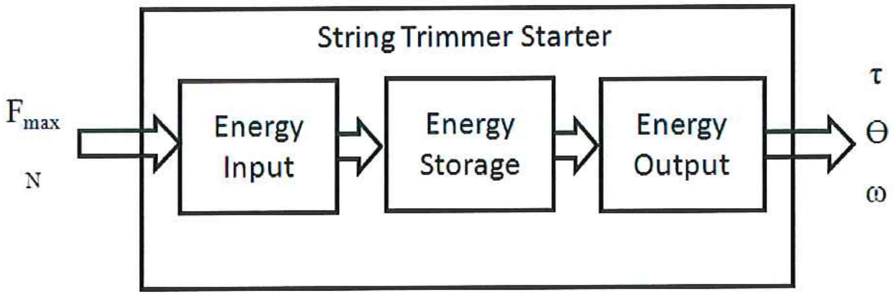


Figure 1: Top-level block diagram of the string trimmer starter showing the three subsystems.

The starter design uses a gear and a plunger (rack) to charge a power spring, while a ball-bearing, clutch, freewheel (one-way bearing), and a ratchet mechanism facilitate the charging, locking, and release of the power spring. A 6.2 inch diameter gear is selected for the design. A plunger (rack) of length 7 inches is placed against the gear, akin to a rack and pinion alignment. This transforms the rectilinear motion of the rack to the rotational motion of the gear. A tension spring is used to restore the plunger to its original position after the plunger is pushed. A high performance carbon steel power spring with an external diameter of 4 inches and a width of 1.25 inches is chosen to store the energy required to turn the crank shaft. Based on information provided by Sandvik Materials Technology, a torque of 100 lb_f-in and 3.5 turns is provided by the selected power spring. A steel free-wheel with an internal diameter of ½ inch and an external diameter of ¾ inch is placed between the gear and the shaft to allow rotation of the axle in only one direction when the gear is engaged. An auto-disconnect clutch is selected to fit the axle diameter of ½ inch. The clutch disconnects the spring from the gear during the power spring release process, therefore, reducing the load applied to the spring. A ratchet device allows for the spring to retain its potential energy between consecutive plunges and allows the operator to release the spring once it is charged. A more detailed specification of all the components used in the design is listed in Appendix F.

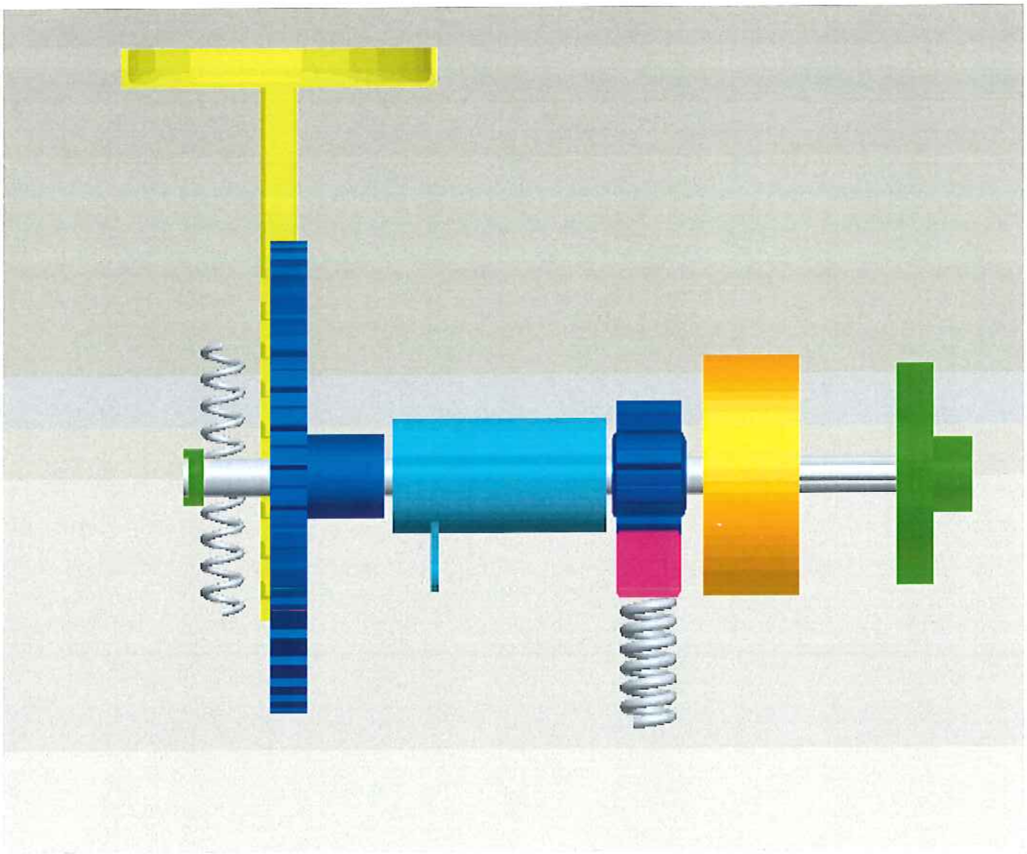
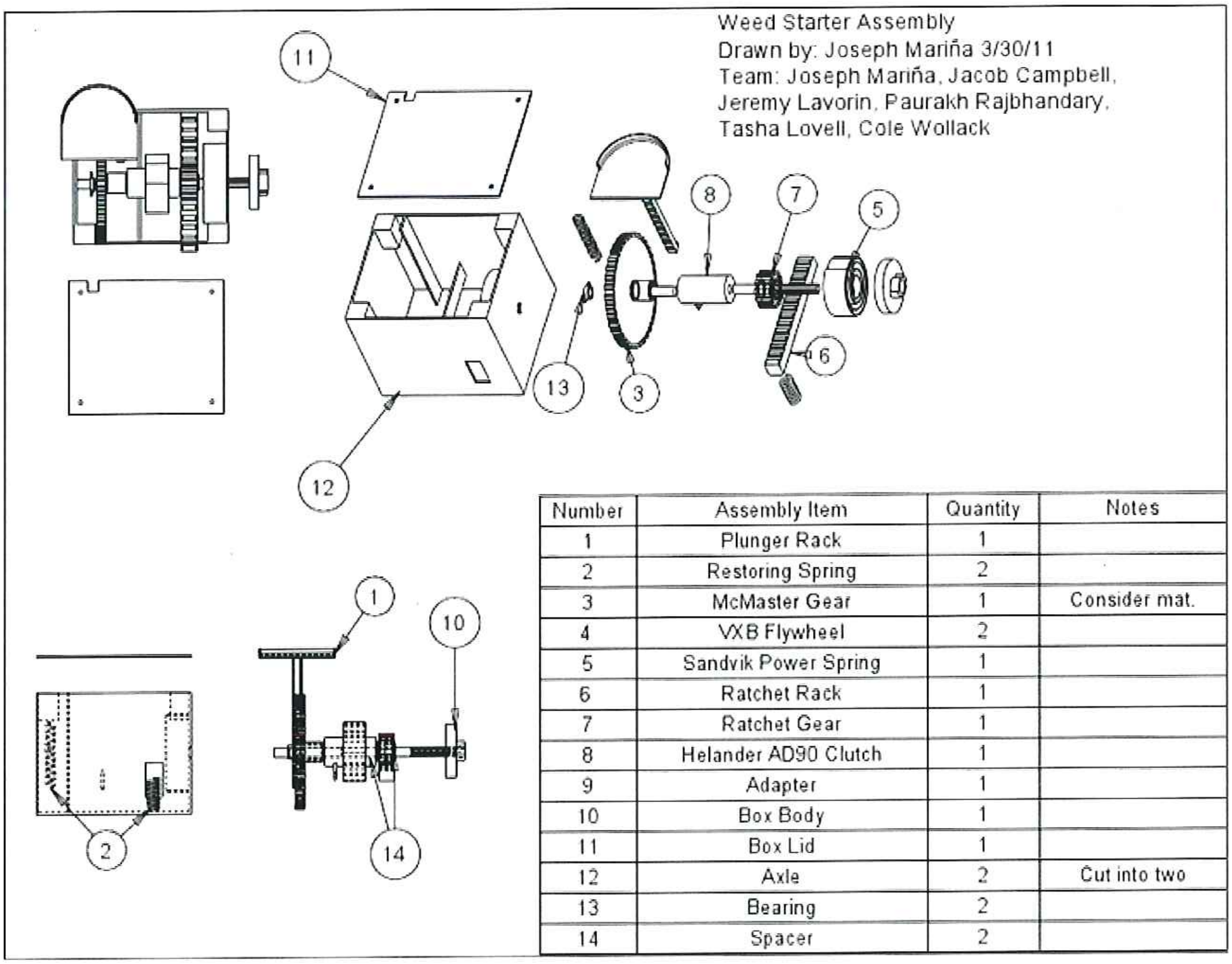


Figure 2: Pro/E drawing of the starter design showing internal components. Housing material is not shown in the figure for illustration purpose.



Weed Starter Assembly
Drawn by: Joseph Mariña 3/30/11
Team: Joseph Mariña, Jacob Campbell,
Jeremy Lavorin, Paurakh Rajbhandary,
Tasha Lovell, Cole Wollack

Number	Assembly Item	Quantity	Notes
1	Plunger Rack	1	
2	Restoring Spring	2	
3	McMaster Gear	1	Consider mat.
4	VXB Flywheel	2	
5	Sandvik Power Spring	1	
6	Ratchet Rack	1	
7	Ratchet Gear	1	
8	Helander AD90 Clutch	1	
9	Adapter	1	
10	Box Body	1	
11	Box Lid	1	
12	Axle	2	Cut into two
13	Bearing	2	
14	Spacer	2	

Figure 3: Assembly of the string trimmer design with all components labeled.

The device is aligned to the rear surface of the string trimmer by a custom made aluminum attachment. The dimensions of the design are selected such that that the cross sectional area of the device is comparable to the cross sectional area of the T272 engine's framework. Shindaiwa T272 user manual recommends setting the string trimmer on the ground to start the engine when using the recoil cord-pull mechanism [4]. Goodwill Industries also mentions that most of their employees using the string trimmer start the engine in the posture shown in Fig. 4. Considering these factors, the design is crafted such that it should be placed flat on the ground before the operator compresses the plunger. However, due to time constraints, a plate that would extend under and behind the case was unable to be constructed to completely stabilize the design for use.

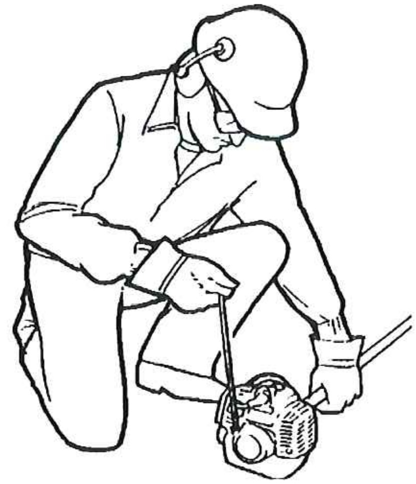


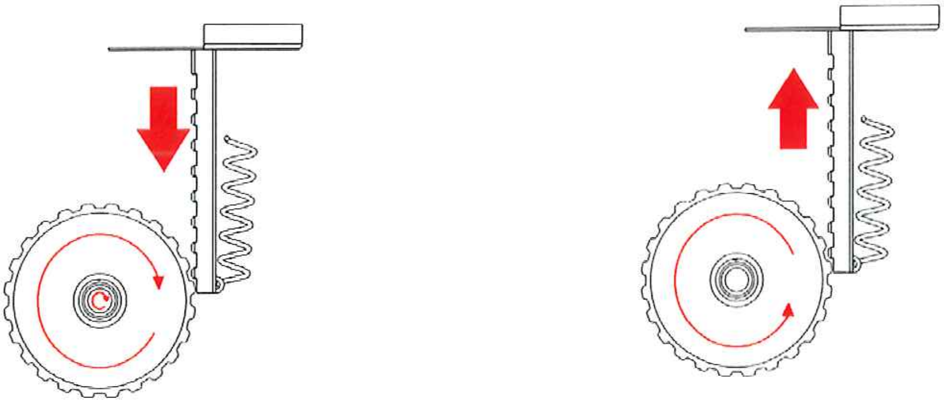
Figure 4: A picture from Shindaiwa T272 user manual showing recommended posture for using recoil cord-pull mechanism [4].

3 Subsystems Design

The design is divided into three subsystems based on their functionality, as shown in Fig. 1. The energy input sub-system consists of a plunger, a gear, and a free wheel that allows the axle to rotate only in one direction. The energy storage sub-system consists of a ratchet device and a power spring that allows the energy to be stored with successive plunger compression. The energy output sub-system is comprised of an auto-disconnect clutch, a ratchet release mechanism, and an aluminum adapter that allows the spring's energy to be successfully delivered to turn the engine's crankshaft.

3.1 Energy Input System

The energy input subsystem converts successive rectilinear thrusts provided through the plunger into the rotational motion of the axle. A freewheel (one-way bearing), placed between the gear and the axle, as shown in the Fig. 3, allows the axle to rotate in one direction while restraining its rotation in the opposite direction. An illustration of the mechanism is shown in Fig. 5. When the operator depresses the plunger, the gear catches onto the axle, thus rotating the axle in clockwise direction. When the plunger restores back to the original position, the gear turns in the counterclockwise direction, but the free-wheel does not allow the axle to rotate with the gear. As a result, the axle remains stationary during the restoring cycle.



(a) (b)

Figure 5: An illustration of freewheel mechanism in the energy input subsystem. (a) The axle rotates when the plunger is pushed down. (b) The axle does not rotate when the plunger restores (notice that no direction arrow is included for the axle in (b)).

With the aforementioned design, the plunger will have to be fully pushed 30-40 times in order to store sufficient energy in the spring. The number of plunge compressions required to fully charge the power spring is related to the gear size; the derivation of the relationship is illustrated in Appendix C and D.

3.2 Energy Storage System

The energy storage subsystem uses a ratchet device to lock the spring in position so that energy is stored in the power spring over each successive push cycle. The ratchet device is located on the spring axle between the clutch and the power spring, as shown in the Fig. 6. When the plunger is depressed, the clutch engages the gear axle with the spring axle and they both rotate in the spring-charging direction. However, a ratchet is required to prevent rotation of the spring axle in the opposite direction, so that the spring does not unwind before it has been fully charged. The ratchet mechanism is composed of a single-directional bearing, a small (1" outer diameter) spur gear, and a rack with matching pitch. The single-directional bearing is press-fit inside the spur gear and acts as a rotational control between the spring axle and the spur gear. When in the locked position, the rack meshes with the gear.

As the spring is charged, the single directional bearing between the spring axle and the spur gear slips so that the axle can rotate freely while the spur gear remains stationary. But the single-directional bearing engages with the axle as the spring resists deformation. The spur gear is able to rotate with the axle as the spring tries to turn the axle in the energy-releasing direction. However, the interaction between the spur gear and the rack causes the spur gear to remain stationary yet again. This prevents the spring axle from rotating in the energy-releasing direction, allowing the spring to hold its charge while the plunger is restored to its original position between plunges. Once the spring has been fully wound, the user can release the spring and its energy by unlocking the ratchet mechanism. This action merely consists of disengaging the rack from the gear. One end of the rack extends beyond the casing via a square hole, and the user directly shifts the rack away from the spur gear. By unlocking the ratchet mechanism, the spring rotates the crankshaft with its full torque and rpm to start the string-trimmer engine.

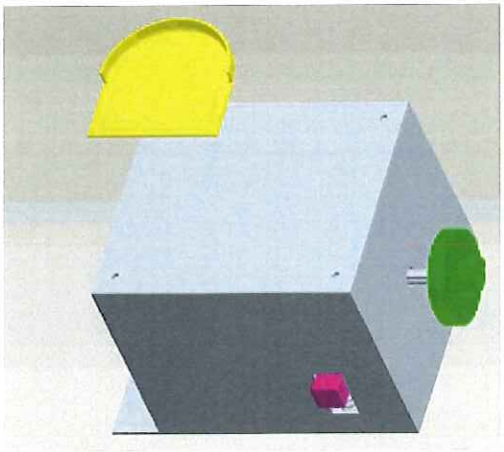


Figure 6: Ratchet/release mechanism used in the design to lock and release the spring.

3.3 Energy Output System

The energy output subsystem consists of a clutch, a ratchet control, and a driver connected to power spring end of the axle. The auto disconnect clutch, AD90, disconnects the energy input subsystems when the spring releases the energy to the engine's crankshaft, thereby reducing the load to the spring [5]. The clutch is able to disengage due to an inner spring inside the clutch that allows rotation in one direction (spring compresses around inner axle of clutch and spins output shaft) but free spins in the other (spring loosens and free-spin is achieved). The operator can use a ratchet control to lock the spring when charging and to release the spring once it is fully charged. The ratchet device is categorized under the energy storage subsystem whereas the ratchet control is categorized under the energy output subsystem. This is because the subsystems are based on functional categorization of each component. In other words, the ratchet device locks the power spring and helps in the energy storage process, while the ratchet control allows the operator to release the lock and output the energy of the spring. An aluminum adapter connects the spring axle from the device to the string trimmer's crank-shaft.

Once the ratchet control lock is released, the power spring will release its stored energy in the form of rotational kinetic energy by rotating the axle until the spring returns to its natural position. In this process, the axle that is connected to the crankshaft provides sufficient torque and angular displacement to the engine to start the engine.

3.4 Integration

A rectangular box of dimension 6.58" x 7.08" x 7.92", made up of 1/16th inch thick aluminum, is selected for the design. This box has been designed to have 4 walls, a base, and a detachable lid. The gear axle is connected to a ball-bearing affixed to the back side of the box, and at other end, it is connected to the clutch. The power spring casing, attached to the box, is fabricated from aluminum to withstand high stress caused by the spring's restoring force. The spring axle is connected to the output of the clutch at one end, and to the arbor of the power spring at the other end. The arbor in this case is a custom made 1 inch spacer with a slit cut into it to allow the spring to slide in. To secure the spring inside this spacer, a strip of metal was cut and wrapped around the inner arm of the spring and then welded to the spacer to ensure the spring will not separate from the spacer during operation. Also, a plastic shield was constructed to cover the spring in order to avoid axial deformation of the power spring in which it tends to form a cone shape while being charged.

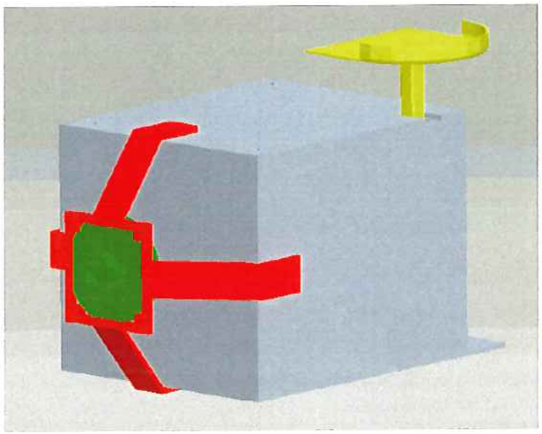


Figure 7: Pro/E solid model of the power spring starter with attachment.

The box will interface with the string trimmer through a custom made aluminum attachment seen in Fig. 7. The device is designed to attach to the string trimmer using 4 screws that will go into pre-existing threaded holes. These holes currently affix the existing cord-pull starter box to the string trimmer. The attachment will interface to the box with 4 metal pull down latches on the outside of the box allowing easy removability once the string trimmer has been started. Pro/E model of the string trimmer retrofitted with the power spring starter is shown in the Fig. 8.

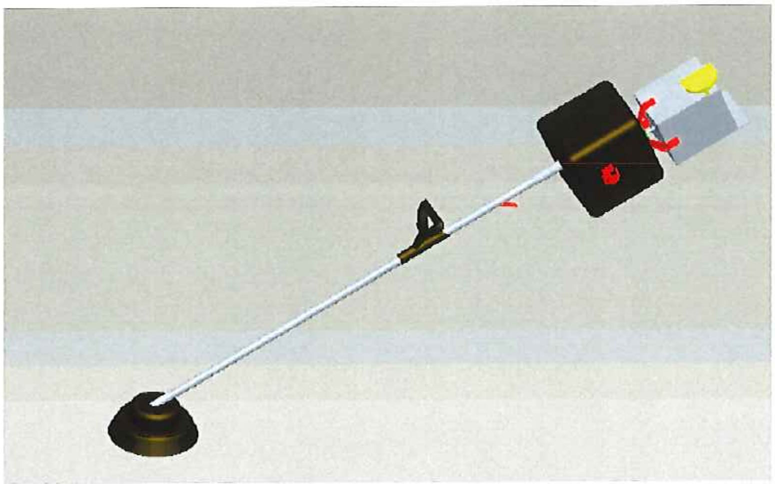


Figure 8: Pro/E solid model of the string trimmer retrofitted with the power spring starter.

3.5 Original Design

Our final design is very similar to the original design, varying only in choices in components and not in functionality. The final design, like the original design, is a power spring mechanism built to start the string trimmer using a plunger to charge the power spring. There have been 3 major changes between the original design and the final, however. Instead of a metal and plastic 2-piece box design, there is a single, solid box made of aluminum with an aluminum lid. This was done to allow easier accessibility to all components of the design. Secondly, the ratcheting mechanism is no longer a boot/pull plug design, and has been replaced by a gear/rack design. This was done to create a more structurally sound releasing mechanism as problems arose with the original in testing. Lastly, unlike the prototype design in which there was no attachment component, the final design has a custom made aluminum attachment that interfaces to the string trimmer via 4 set screws and to the power spring box with 4-metal pull down latches (Fig. 7).

4 Methods

Each subsystem of the design was tested and verified to be working properly inside the prototype before the overall design constraints and criteria could be tested. The objective of testing the design focused primarily on verifying that the prototype met the design constraints and criteria before implementation into the final design. After these tests of the torque and RPM, the final design can be built with relative confidence of success.

4.1 Initial Testing

Firstly, testing had to be done to ensure that the right materials could be acquired that would match the parameters (torque, angular velocity, and angular rotations). Using a power watt meter, a data acquisition program, power drill, and a digital tachometer, several tests were done to check the power and the RPMs required to successfully start the string-trimmer. Using the DAQ along with EXCEL and the common relationship shown in Eq. 1 of Appendix A where power relates to torque, the values for the torque were evaluated. The angular velocity was directly read off the tachometer to verify the value that started the string-trimmer. The results are shown in Table 1 of Appendix A of the torque and angular velocity for these specific tests.

For the angular revolution test, the existing cord-pull mechanism was shown to turn a maximum of 4.5 turns. However, repeated starts of the string-trimmer showed that the engine could be started with as little as 3.5 turns. This would in turn be the theoretical maximum for angular turns that the design had to meet in order to start the string-trimmer instead of the initial 4.5 turns.

4.2 Subsystems

After the prototype was assembled, the three subsystems are checked individually. The energy input subsystem, which is comprised of a gear, press-fitted with a one way bearing, along with a plunger, allows the operator to turn the axle with successive plunges. The axle is verified to rotate in one direction while the plunger is plunged and to be stationary when the plunger returns to the normal position. This verification proves the function of one way bearing present between the gear and the axle. The test of the energy storage subsystem verifies that the energy of the operator is stored in the power spring and locked by an appropriate ratchet device. The spring-axle is passed through a smaller gear press-fitted with one way bearing. A rack is used to ratchet or lock the axle in position when the power spring exerts restoring force. In order to test this storage subsystem, while the plunger is pushed, the rack should be able to lock the spring-axle. The test on the energy output system should verify that the rack can be easily disengaged to allow the power spring to release its spring-potential energy. Also, he mechanics of the clutch should be verified to be working. The clutch should engage the two pieces of the axle when torque is provided through the plunger. However, it should disconnect the two axles when the spring is released, so that the energy input system is detached from the energy output system.

4.3 Complete System

After each of the subsystems is tested and verified to be working properly, the assembled design is subjected to the design parameter testing and the field testing. In the parameter testing, the torque output, the RPMs, and the number of turns will be measured and compared against the design criteria. In order to test the RPM of the output axle, initially, an IR tachometer was used. However, IR tachometer was unable to acquire consistent RPM reading because the release process of the spring was abrupt and did not provide sufficient sampling time. Therefore, a HD camera (Kodak Zi8) at the setting of 720 p and 60 fps was used to record the turning of the axle, as the spring is released. The video was then analyzed to deduce the time required for the spring to turn the axle by the known number of revolutions. This allowed the RPM to be calculated. The torque provided by the design is tested by using a mechanical click-type torque wrench that is set at a value of 100in-lb$_f$, the torque required to start the string trimmer. The output axle of the design is fitted into the socket of the torque wrench. By charging the power spring and holding the torque wrench, there should be an audible click if a torque of 100in-lb$_f$ is met or exceeded. This test would then verify that the design was outputting enough torque to start the string trimmer.

After testing subsystems and design parameters, final part of the test is the field test, which involves attaching the design to the string trimmer, and using it to start the string trimmer. Using the special attachment design, the box will be firmly attached to the hind surface of the string trimmer. This test involves verifying whether the design can consistently start the string trimmer, and exact alignment of the design, and ease of removing the attachment.

5 Results

Every test of the subsystems and main design gives results that will help the overall design further. Each result shows what needs to be fixed and what works well, helping to improve the final design. All of these tests, however, were performed on the prototype and not in the final design.

5.1 Subsystems

Testing of each subsystem (i.e. energy input, energy storage, and energy output) yielded qualitative results rather than quantitative. Such qualitative results follow from the method by which subsystem functionality was verified. The functionality of each subsystem was confirmed using visual inspection.

For instance, the vertical displacement of the plunger was examined to see if the linear spring connecting the plunger and case was working properly. After several depressions of the plunger, it was obvious that the linear spring was applying a restoring force on the plunger; thereby bring the plunger back to its original position as the spring returned to equilibrium. This test indicated that the design of the connections between the plunger and spring, and spring and housing were sound. The plunger also contacted the gear properly, rotating it in the clockwise direction as expected. The one-way bearing was also examined and confirmed in this test to ensure that it would allow rotation of the gear and axle in one direction, but allow the plunger to move back up and only spin the gear and bearing, but not the axle.

The energy storage system was observed to make certain that the ratchet locking mechanism was correctly functioning as well as the power spring. With the ratchet rack properly locked, the plunger would depress, causing the spring to be charged. This was made possible due to the correctly functioning spur gear and one-way bearing. The axle was allowed to correctly free spin in the power spring charging direction, but stop when no more force was being put into the plunger and gear. This obtained positive test results for the energy storage system.

Finally, the energy output system was also checked to guarantee that every mechanism was working as designed. The key component in this subsystem was the AD90 auto disconnect clutch. With all necessary connection with the two axles, the clutch was tested. When energy was inputted into the clutch and spring, the clutch would act like a freewheel and allow everything to spin. However, once the system is fully charged, the ratchet control would be released and in this small time frame, the clutch was observed. It successfully allowed only the spring axle to spin and not the gear axle. This confirmed it was functioning as it was designed. Finally, the adapter that would connect to the string-trimmer was tested. Because the adapter was already designed for the string-trimmer, quickly observing it inside the string-trimmer confirmed rotation in one direction, but slippage in the other – much like a one way bearing.

5.2 Complete System

With all the components working together properly as designed, the final output parameters—torque, angular velocity, angular turns, maximum force, weight, and size—could be calculated. The final estimated production cost of the device could also be calculated with a final prototype fully constructed and operational.

As mentioned previously, torque output by the device was measured with a mechanical torque wrench. Several torque test trials, where a torque wrench was attached to the output axle of the design indicated that the device output at least 100in-lb$_f$ because the mechanical torque wrench issued a click while rotating the output axle of the device indicating 100in-lbf was present. The click of the torque wrench occurred at about two revolutions of the axle.

By charging the device, as would a user, and releasing the stored energy to rotate the axle successfully yielded 3 angular turns of the axle at the output. However, the ring that enclosed the spring cracked and destabilized the power spring as the axle was taken past 3 angular turns in an attempt to reach the theoretical maximum of 3.5 angular turns. Thus, 3 angular turns was determined to be the maximum.

At first, output angular velocity was tested using a digital tachometer, but the tachometer yielded unusually low values such as 91 RPM in one trial and 240 RPM in another. A suspicion arose that the tachometer could not accurately detect highly transient processes such as that occurring when the axle rotated as the spring was released. To combat this problem, the rotation of the axle at the output was recorded using a video camera capturing images at 60 frames per second (60 fps). Two trials were completed and the videos were analyzed using the video editing software Sony Vegas. This method, called videogrametry, yielded an angular velocity of 900 RPM.

Final output values for the maximum force necessary to depress the plunger on the last push were not obtained because the welding that retained the spring cracked, making further testing impossible.

The weight of the device was measured using a standard scale. The final weight of the device, with all of the components in place, was 16 $\mathrm{lb_m}$.

The estimated final production cost of the device was calculated by obtaining quotes from the power spring, gear, and bearing manufacturing companies used for 1000 units of each component. The resulting total came to about $250.

6 Conclusion and Recommendations

Starting a string-trimmer requires a significant amount of arm strength using the traditional pull-cord mechanism. However, a large percentage of Goodwill Industries' employees claim a disability, which includes low arm strength and low dexterity. Low arm strength and dexterity bars these employees from using string-trimmers, due to the requirements of the pull-cord mechanism. Goodwill Industries would like a device that reduces the force required to start a string-trimmer, thereby reducing the necessary arm strength to operate such string-trimmers. This alternative string-trimmer starting device would allow Goodwill Industries to employ a larger pool of workers in lawn maintenance positions because they could rely on employees with low arm strength and dexterity to start string-trimmers effectively. An engineering design project was undertaken to create such a device. Harnessing the mechanical energy in a spring, whit the user charging the device with their foot successfully eliminated the need for the high upper body strength requirement when operating these string trimmers.

Our design did meet the safety and monetary development cost constraints. The final design was produced within the budget of $1200 and safely guarded the use against malfunctions or misfires. The mobility constraint was not met due to the weight so as stated above in the report a detachable design was implemented. The monetary constraint of a production unit being under $100 was not met. Finally our constraint of durability and having the unit withstand the outdoor conditions was not able to be verified do to the limited amount of time.

Our design was able to meet the torque, angular velocity and size constraints. The design was not able to meet the angular turn and weight constraints. Testing on the maximum force required was not able to be tested due to the weld that held the housing for the spring broke before this testing phase was conducted. The table below shows the comparison of the constraints and criteria set at the start of the project versus the empirical design performance collected through testing.

Table 1: Empirical performance of the design compared to the design criteria and constraints.

Parameter	**Constraint/Criteria**	**Empirical Design Performance**
Torque (τ) [lb$_f$-in]	54.9	>100
Angular turn (Θ) [revolution]	*4.5*	*3*
Angular velocity (ω) [RPM]	800	900
Maximum Force Required (Fmax) [lb$_f$]	35	-
Weight [lb]	10	15
Size [in^3]	10 x 10 x h	7 x 7.5 x 6.5
Development cost [$]	$1200	$1061
Production Cost [$]	$50	-

Note: The parameter h is the width of the design that is minimized.

Lots of progress was made during the two semesters working on the alternative starting mechanism for string trimmers. A final design was produced relieving the user of the upper body strength requirement to start a string trimmer yet more work needs to be done to make design a field ready product. This work is mainly in the field of optimization. This optimization mainly revolves around the weight of the design. Selecting plastic parts for the casing, gears and the racks would allow a drastic reduction in weight. Further testing and analysis on the stresses involved in the system need to be analyzed when choosing the optimal solution. Optimization may also be conducted on reducing the length of the design, possibly by rearranging components so that they are not all placed linearly throughout the system. Finally many malfunctions occurred during testing due to the auto disconnect clutch not auto disconnecting. Our team has determined that this was due to an unpredicted torque on the clutch where the two axles meet; more support is needed on the clutch insuring that the axels come together perfectly linearly to avoid the clutch issues. Though optimization of weight and better support on the clutch it is believed that this design would be a plausible product to implement in the field.

7 Bibliography

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A Appendix: Tables

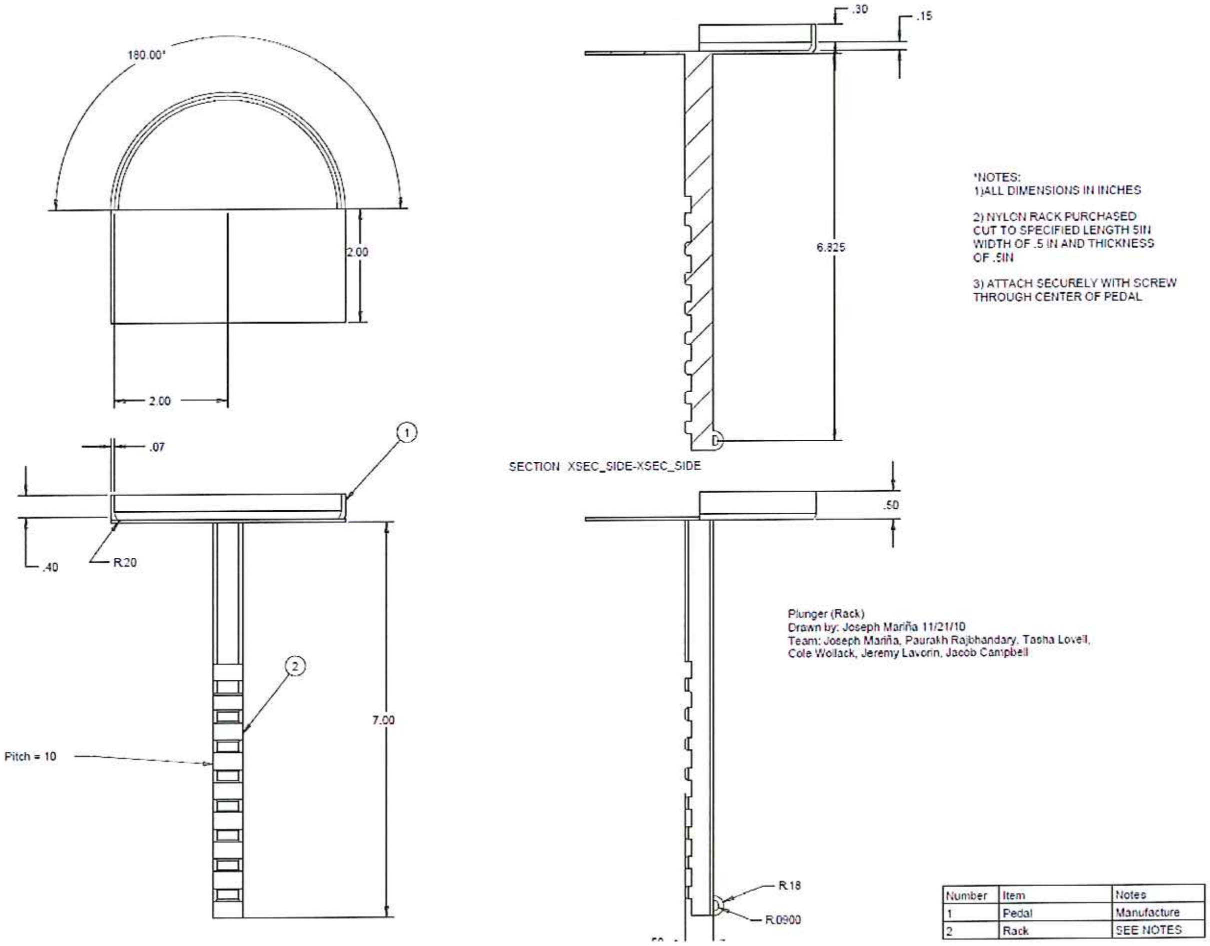
Table A-1: Test result determining the design criteria.

Run #	**P** **[W]**	**ω** **[RPM]**	**τ** **[N-m]**
1	485	750	6.18
2	497	980	4.84
3	452	480	8.99
Average	478	737	6.20

Note: P is the power reading of the watt-meter, ω is the angular velocity of the crankshaft measured using IR tachometer and τ is the torque delivered to the crank-shaft derived using the Eq. 1 [5].

$$\tau = \frac{60 * P}{2 * \pi} \quad (1)$$

B Appendix: Engineering drawings of components



*NOTES:
1)ALL DIMENSIONS IN INCHES

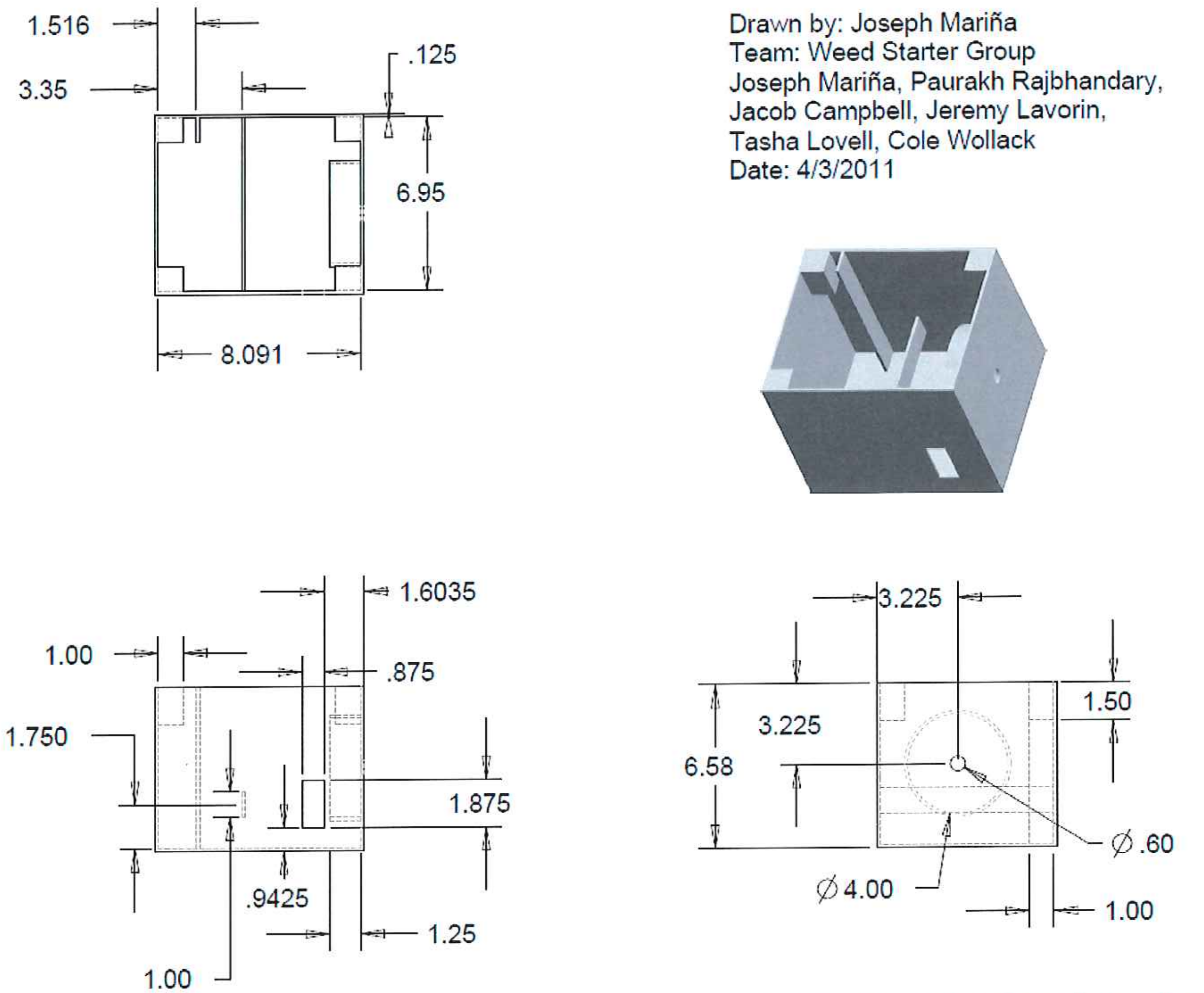
2) NYLON RACK PURCHASED
CUT TO SPECIFIED LENGTH 5IN
WIDTH OF .5 IN AND THICKNESS
OF .5IN

3) ATTACH SECURELY WITH SCREW
THROUGH CENTER OF PEDAL

Plunger (Rack)
Drawn by: Joseph Mariña 11/21/10
Team: Joseph Mariña, Paurakh Rajbhandary, Tasha Lovell,
Cole Wollack, Jeremy Lavorin, Jacob Campbell

Number	Item	Notes
1	Pedal	Manufacture
2	Rack	SEE NOTES

Figure B-1: Engineering drawing of plunger (rack) with dimension in inches.

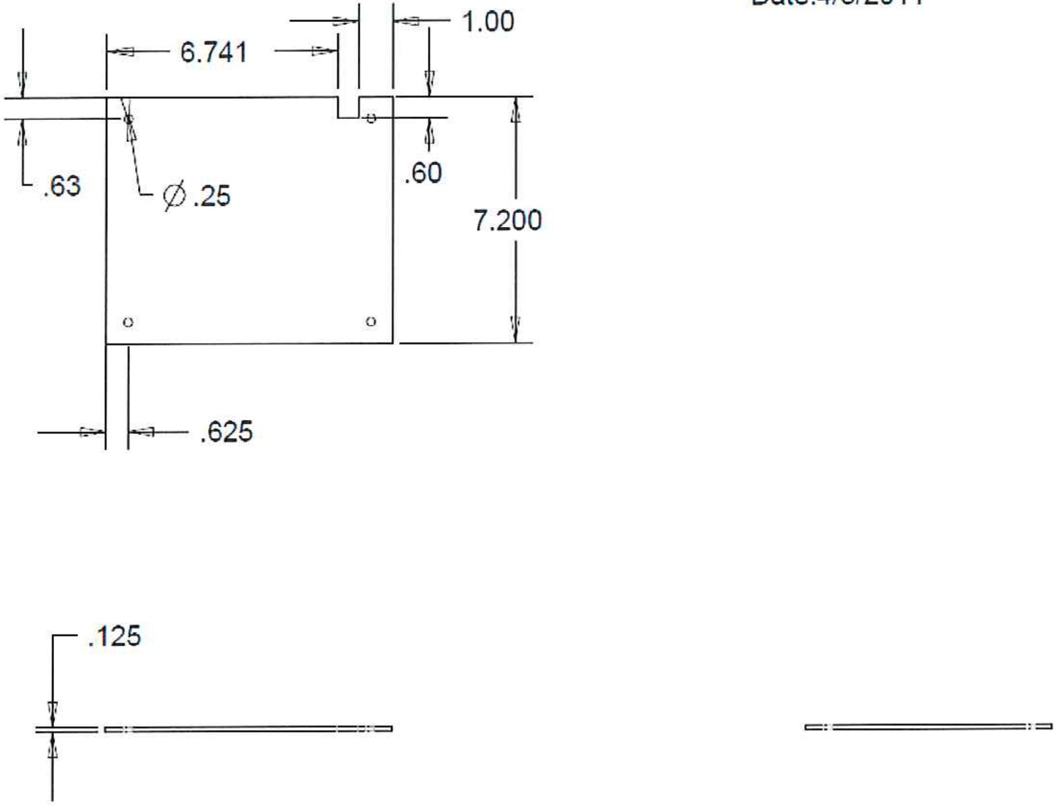


Drawn by: Joseph Mariña
Team: Weed Starter Group
Joseph Mariña, Paurakh Rajbhandary,
Jacob Campbell, Jeremy Lavorin,
Tasha Lovell, Cole Wollack
Date: 4/3/2011

NOTE: ALL DIMENSIONS IN INCHES

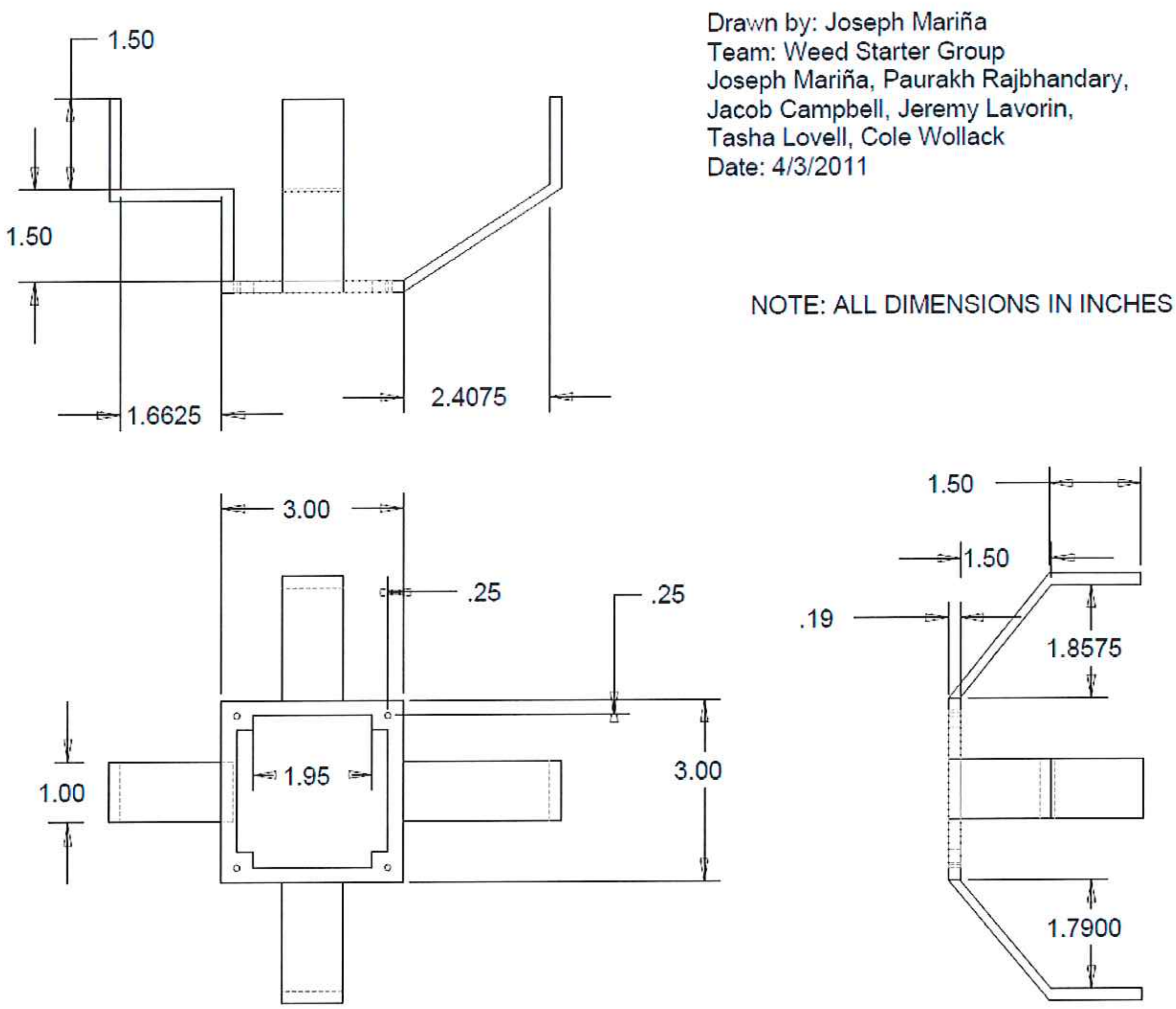
Figure B-2: Engineering drawing of the aluminum adapter with dimension in inches.

Drawn by: Joseph Mariña
Team:Weed Starter Group
Joseph Mariña, Paurakh Rajbhandary,
Jacob Campbell, Jeremy Lavorin,
Tasha Lovell, Cole Wollack
Date:4/3/2011



NOTE: ALL DIMENSIONS IN INCHES

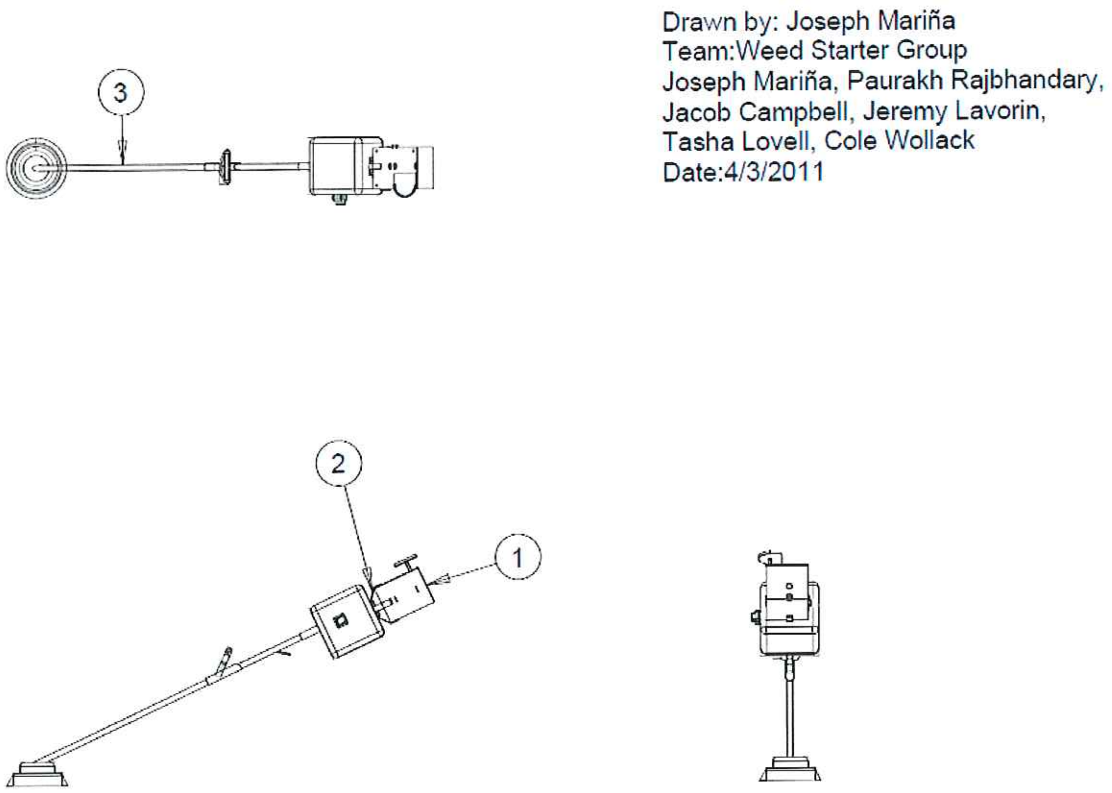
Figure B-3: Engineering drawing of the case lid with all dimensions in inches.



Drawn by: Joseph Mariña
Team: Weed Starter Group
Joseph Mariña, Paurakh Rajbhandary,
Jacob Campbell, Jeremy Lavorin,
Tasha Lovell, Cole Wollack
Date: 4/3/2011

NOTE: ALL DIMENSIONS IN INCHES

Figure B-4: Engineering drawing of the attachment plate with all dimensions in inches.



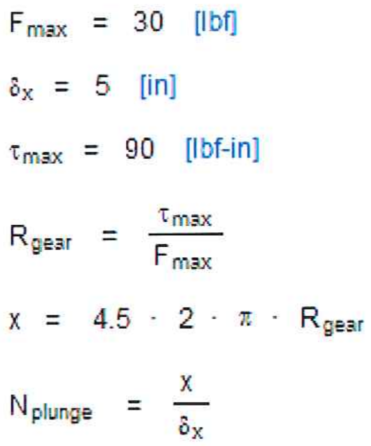
Number	Assembly Component	Notes
1	Gear Box Assembly	See Gear Box Assembly Drawing
2	Claw	See Attachment Mechanism Drawing
3	Weed Trimmer	Generic

Figure B-5: Engineering drawing of the retrofitted string trimmer with power spring starter.

C Appendix: Sample Calculations

Spring criteria	Torque(τ) = 8.33 lb_f-ft (from Table A-1)
	Angle turns(θ) = 4.5 cycles (verified by counting the number of cycles the manufacturer's pull string starter rotates when the cord is completely pulled)
Gear size determination	$\tau = F_{max}*R$ [5] where, τ is the maximum torque required, F_{max} is the maximum operator force required, and R is the radius of the gear.

D Appendix: EES Analysis of Maximum Input Force and the Gear Size



$$F_{max} = 30 \quad [lbf]$$

$$\delta_x = 5 \quad [in]$$

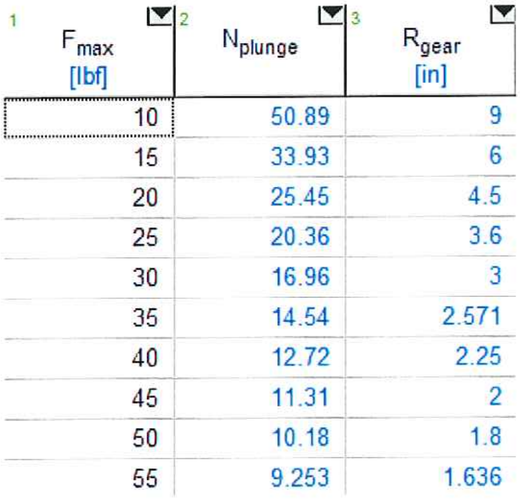
$$\tau_{max} = 90 \quad [lbf\text{-}in]$$

$$R_{gear} = \frac{\tau_{max}}{F_{max}}$$

$$x = 4.5 \cdot 2 \cdot \pi \cdot R_{gear}$$

$$N_{plunge} = \frac{x}{\delta_x}$$

Figure D-1: EES Screenshot of formatted equation used for gear and maximum input force.



1 F_{max} [lbf]	2 N_{plunge}	3 R_{gear} [in]
10	50.89	9
15	33.93	6
20	25.45	4.5
25	20.36	3.6
30	16.96	3
35	14.54	2.571
40	12.72	2.25
45	11.31	2
50	10.18	1.8
55	9.253	1.636

Figure D-2: EES screenshot of the parametric table used to analyze effect of maximum force on the number of plunges and gear size.

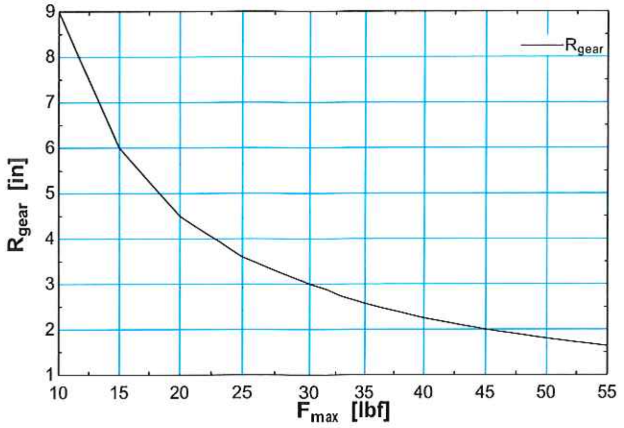


Figure D-3: Trend showing effect of increasing the maximum plunge force on the gear size.

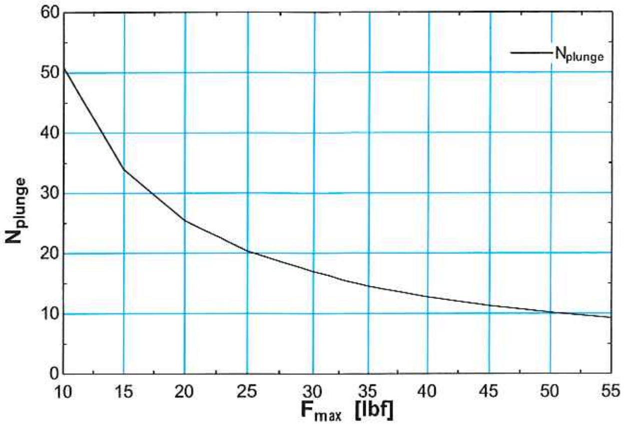


Figure D-4: Trend showing effect of increasing the maximum plunge force on the number of plunges required to charge the spring.

E Appendix: Final Budget Spreadsheet

Expenses

Date	Vendor	Item Description	PO #	Part #	Status (Planned/ Pending/ Cleared)	Budgeted Amount	Actual Amount	Status (Check one)			
								Internal	Dept Purchase Order	PCARD	Reimbursement
11/19/2010	McMasterCarr	Steel Rack	3 189878	6295K17	Cleared	$35	$28				x
11/19/2010	McMasterCarr	Steel Gear	3 189878	6325K9	Cleared	$60	$60				x
11/19/2010	Sandvik Materi	Power Spring		NA	Cleared	$200	$200	x			
11/19/2010	Tiny Clutch	AutoDisconnect Clutch	13180	NA	Cleared	$175	$173	x			
11/19/2010	VXB Bearings	Single Directional Bearing	100726	RCB081214	Cleared	$20	$16				x
12/10/2010	McMasterCarr	Housing-metal 24"x12"x3/16"	DP Credit	4058T22	Cleared	$50	$80			x	
12/20/2010	McMasterCarr	Housing-plastic 12"x12"x1"	DP Credit	98170A410	Cleared	$50	$34			x	
12/20/2010	McMasterCarr	Axle	DP Credit	4437T111	Cleared	$10	$6			x	
12/20/2010	McMasterCarr	Linear Spring	DP Credit	9432K119	Cleared	$5	$2			x	
12/20/2010	VXB Bearings	Bi-Directional Bearing	100726	6384K61	Cleared	$10	$7				x
12/20/2010	McMasterCarr	Ratchet Spring	DP Credit	9657K88	Cleared	$5	$1			x	
12/20/2010	McMasterCarr	Ratchet Rod	DP Credit	6720K121	Cleared	$5	$3			x	
12/20/2010	Lowes	Hardware (12 screws)			Pending	$10	NA				
1/28/2010	VXB Bearings	One-Way Bearing	104278	Kit8658	Cleared	$10	$10				x
1/28/2010	VXB Bearings	Shielded Bearing	104278	Kit8522	Cleared	$15	$12				x
1/29/2010	McMasterCarr	Axle 1"	0129PRAJBHAN	8890K202	Cleared	$30	$30				x
3/9/2010	Latch Comp	Latches			Pending	$15	$12				x
3/9/2010	Amazon	Bearings	103-1935002-	RCB081214	Cleared	$50	$48				x
3/9/2020	Metal Depot	Aluminum Plate	6881698	S318	Cleared	$50	$51				x
3/9/2010	McMasterCarr	Ratchet Gear/rack	0310LOVELL	6325K22	Cleared	$40	$39				x
3/22/2011	Tiny Clutch	Clutch Repair			Cleared	$30	$73				x
3/31/2011	Cardona Weldir	Welding			Cleared	$200	$175				x
4/25/2011	Ginny's Printinc	Printing			Cleared	$10	$8	x			
Total Expenses						$1,085	$1,069				

	Budgeted	**Actual**	**Planned**
Budget Remaining	$115.00	$504.08	$935.92

F Appendix: Bill of Materials.

Part #	Part Name	Specification	Price [$]	Estimated Weight [lb_f]
1	Rack (plunger)	Steel 14-1/2 Deg Pressure Angle Gear Rack 10 Pitch 1" Face Width 7" Length	28	0.5
2	Restoring Spring		5	0.3
3	Gear	Steel Plain Bore 14-1/2 Deg Spur Gear 10 Pitch 60 Teeth 6.2" Pitch Diameter 7/8" Bore	60.23	4.5
4	Free-Wheels	ID (inner diameter)/Bore=1/2" OD (outer diameter)=3/4" Width/Height/thickness=7/8" Item: Needle Roller Bearing One-way Shell Type RCB081214 Size: 1/2" x 3/4" x 7/8" Pitch: 101	16	0.2
5	Power Spring	Material Thickness: 0.055'' Spring Width: 1.25'' Arbor Diameter: 1.25'' Spring Diameter: 6.0'' Torque: 100 lb_f-in Turns: 4.5 Material: High Carbon Steel	200	1.5
6	Ratchet Gear	Ratchet length: 1.0 '' Ratchet Height: 1.0'' Material: Steel	18	0.3
7	Ratchet Release Rack	Length: 8" Rack Width: 1.0''	21	0.4
8	AD Clutch	Clutch length: 2'' Clutch outer diameter: 1.5''	173	0.75
9	Spacer	Inner diameter: 0.5'' Outer diameter: 0.95''	5	0.3
10	Aluminum Attachment	Custom	40	.7

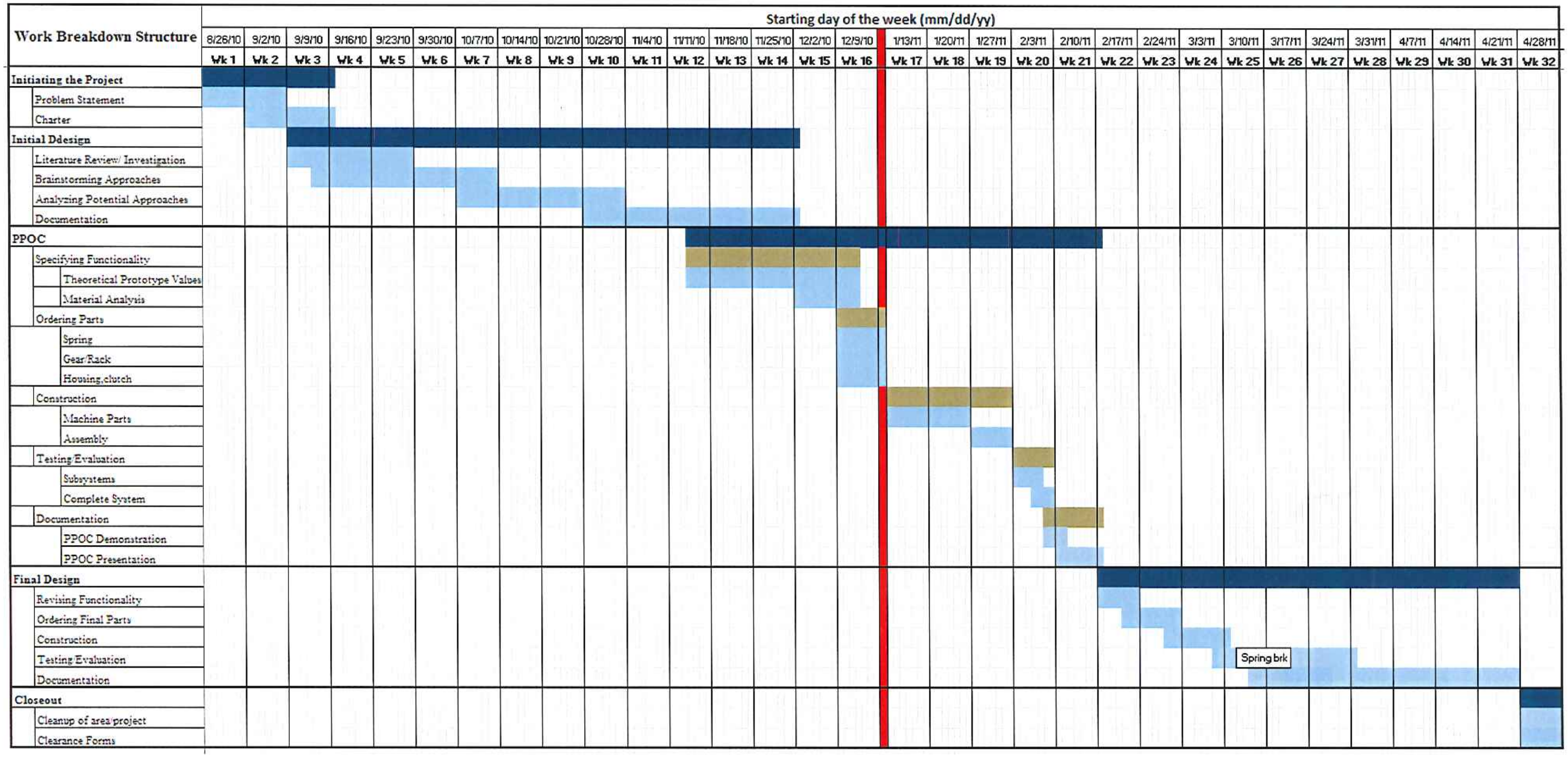
11	Aluminum Box	Height: 6.58” Width: 7.08” Depth: 7.92” Material: Aluminum	51	2
12	Welding	Attachment and Box	175	~0
13	Axle	Diameter: 0.5”	8	0.4
14	Latches	Length: 1.0” Width: 0.5”	15	0.4
15	Bearings		15	0.2
Total			**830.23**	**12.45**

Note: The prices of the products do not include the shipping and handling fees.

G Appendix: Vendors

Name	Phone Number	Website
Amazon	-	amazon.com
All Metric Small Parts	(516)-302-0152	allmetricsmallparts.com
Cardona Welding	(210)-224-8347	-
Home Depot	(210)-545-1431	homedepot.com
McMaster-Carr	(609)-689-3415	mcmaster-carr.com
Metals Depot	(859)-745-2650	metalsdepot.com
Sandvik Materials	(570)-585-7732	smt.sandvik.com
Tiny-Clutch	(860)-669-7953	tinyclutch.com
VXB Bearings	(800)-928-4430	vxb.com

H Appendix: Gantt Chart



I Appendix: Center of Gravity Calculations

	Weight	Total Length	Center of Gravity
String Trimmer	16 lb_m	68 in	49 in
Optimal Design plus Trimmer	12.5 + 16 lb_m	76 in	61 in
Actual Design plus Trimmer	16 + 16 lb_m	76 in	62.5 in
Acceptable Center of Gravity Range 44-58 in			

$$Center\ of\ Gravity = \frac{\Sigma mr}{\Sigma m} \quad (2)$$