The Development of the HANSCycle RLT

Final Report

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Acknowledgements

Team 8 would like to thank the FAMU-FSU College of Engineering for providing the opportunity to further our knowledge in the pursuit of academic excellence in not only this project, but all of our coursework. Special thanks is also given to Dr. Chiang Shih and Mr. Keith Larson for their contributions and insight into this project. Our sponsor, Gordon Hansen, has been a very helpful and involved aid in the design of the RLT prototype bicycle, and all adjustments throughout this fall and spring semesters. The team's research and project has also been assisted by various professors at the College of Engineering, along with the school's Machine Shop. Additional help and expertise was also given by University Cycles, which is a local bicycle shop that specializes in commuter style bikes.

Abstract

Team 8 is dedicated to developing a working HANSCycle, which implements the Reciprocating Lever Transmission (RLT) designed by Gordon Hansen. The goal of the RLT is to improve upon a few aspects of the traditional bicycle. These include two ‘dead spots’ at the top and bottom of a normal pedal rotation, as well as alleviating joint damage to the user from the ‘dead spots’. If successful, the HANSCycle will be both efficient and ergonomically comfortable for the user. Once a working prototype was developed, the team tested it and compared values such as torque, cadence, work, and speed, with values of a traditional bicycle. Initial testing has been promising, as the data suggests favorable power transfer from the user to the road. However, the current size constraints of the initial prototype have led to premature failures. This has been primarily due to the high levels of torque transferred through the RLT, which has caused several components to shear, including most recently, the output shaft. The torque produced by the RLT is greater than a traditional bicycle because of the increased crank-arm length. This project strives to prove that the Reciprocating Lever Transmission can perform as well as or even better than a traditional bicycle, while also causing less stress and damage to the rider’s joints.

Biographies

Team Leader - Nicholas Khayata

Nick is from Cooper City, FL. He will graduate in April 2017 with a B.S. in Mechanical Engineering. He has been a member of the Society of Automotive Engineers for 3 years and is currently the Vice President for the 2016-2017 season.

Financial Advisor - Darren Beckford

Darren is a senior Mechanical Engineering student from Miami Fl. His main role of the group is to manage the budget, as well as follow up with the procurement forms. He will graduate in the spring of 2017 with his B.S in mechanical engineering.

Organization Leader and Webmaster - Alison Pustelniac

Ali is From Pembroke Pines, FL. She is a member of SWE and AIAA, and will graduate in April of 2017 with a B.S. in Mechanical Engineering.

Lead Mechanical Engineer - Michael Kyle Roddenberry

Kyle is currently a Mechanical Engineering student at the FAMU-FSU college of engineering. He is a Crawfordville local, who graduated from Wakulla High School. In addition to studying, Kyle works full time at Werner Hyundai as a Sales and Leasing Consultant. In his free time, he enjoys spending time with his family, his wife Amy, and loves the outdoors.

Team 8 Sponsor - Gordon Hansen

Gordon (gordon.hansen@me.com) is currently studying bicycle infrastructure improvements and intergenerational neighborhood planning, following four decades of private and public sector work in urban planning and design. US Patent 8,763,481 (https://www.google.com/patents/US8763481) was issued to Gordon for a Reciprocating Lever Transmission (RLT) intended to serve as an alternative to electric assisted bicycles, and to serve as a foundation for a new class of bicycles. The RLT allows the use of long pedal crank arms intended to generate significantly increased power, potentially decrease pedaling related knee injuries, and provide rehabilitation applications. Gordon previously sponsored Team 20 in 2016, whose RLT work was judged the "Best Innovation in Design”. Gordon is pleased to sponsor the Team 08, class of 2017, in their work to further improve upon the earlier RLT design work.

1. Introduction

This project is aimed at improving the design of the traditional bicycle mechanism, which may offer a more efficient bicycle experience. Traditional bicycle mechanisms have two "dead" spots, where power is lost and potential joint harm can be done to the user. These "dead" spots are located at the top and bottom of the crank mechanism, and are not ideal for optimum energy-to-power efficiency. This means that while pedaling on a standard bicycle, the user is not only losing power, but also potentially causing harm to themselves in two locations of each full pedal rotation. This loss of power and joint harm is especially magnified when the bicycle is used on an increasing grade, or sloped path. For these reasons, the Reciprocating Lever Transmission (RLT) design has been introduced.

The sponsor of this project, Gordon Hansen, has proposed the new bicycle design which must be built and tested. This design utilizes the Reciprocating Lever Transmission, which consists of two pedals connected to a drive shaft with one-way clutches. This optimizes power efficiency because as one pedal is pushed downwards, the other pedal is simultaneously pushed upwards by means of the RLT mechanism. In addition to this, the pedal cranks will be longer than the average 7" cranks of Traditional bicycles. This will not only make pedaling easier, but will also create more torque. However, it should be noted that last year's HANSCycle team had trouble getting the longer cranks to successfully work with the gears and assembly. This year's team will be working to design a system that successfully functions.

Possible problems that could be encountered include the functionality of the pedal system and testing of the final product. Because of the longer crank arms, stronger shafts and clutches must be used in order to be able to support the increased torque. The team must analyze the material, size, and shape of last year's design in order to find a way to improve the function of the mechanism. Testing the functioning design will also be an important challenge. Because RLT's are fairly uncommon, testing and data are not well documented. The team will need to acquire an accurate testing method, to then be able to compare results with traditional bicycle mechanisms.

2. Problem Statement

"A traditional bicycle is difficult to ride up hill due to its limited torque output and can also be damaging to a rider's joints."

Team 8 has been tasked with developing a working HANSCycle implementing the Reciprocating Lever Transmission (RLT). The goal of this design is to improve upon a few aspects of the traditional bicycle, including two 'dead spots' at the top and bottom of a normal pedal rotation, as well as alleviating joint damage to the user from these dead spots. If successful, the HANSCycle will be more power efficient and ergonomically comfortable for the user. Once a working prototype has been developed, the team must test it and compare values such as power, cadence, work, and speed, with values of a Traditional Bicycle. This project hopes to prove that a reciprocating lever transmission on bicycle can obtain similar results in performance compared to a traditional bicycle, while also causing less stress and damage to the rider's joints.

3. Project Scope

Gordon Hansen, the HANSCycle sponsor, believes his redesign of the traditional bicycle will lead to a new age of bicycling. The goal of the Reciprocating Lever Transmission is to maximize efficiency and ease stress on the user's joints due to the "dead spots" in a traditional bikes transmission. These "dead spots" can cause joint harm and are unconducive to an efficient ascent uphill. He believes that the short crank arms on traditional bikes require more work from the bicycle rider, and has therefore patented his design. The RLT incorporates larger crank arms that can produce more torque and travel in an arc no greater than 100 degrees, which avoids the dead spots. Below, Figure 1 displays the disassembled bicycle components that were used to construct last year's prototype.

Figure 1: Disassembled bicycle components

The bicycle is still intact with many of the above parts, but certain aspects required improvement. Specifically, the output shaft, crank arms, bearings, bolts, ratchet and pawls, chain ring adapter, handlebars, handlebar stem, and seat needed improvements. It was necessary to make many of the RLT components stronger in order to be able to support the increased torque from the longer cranks used on the Reciprocating Lever Transmission seen below in Figure 2.

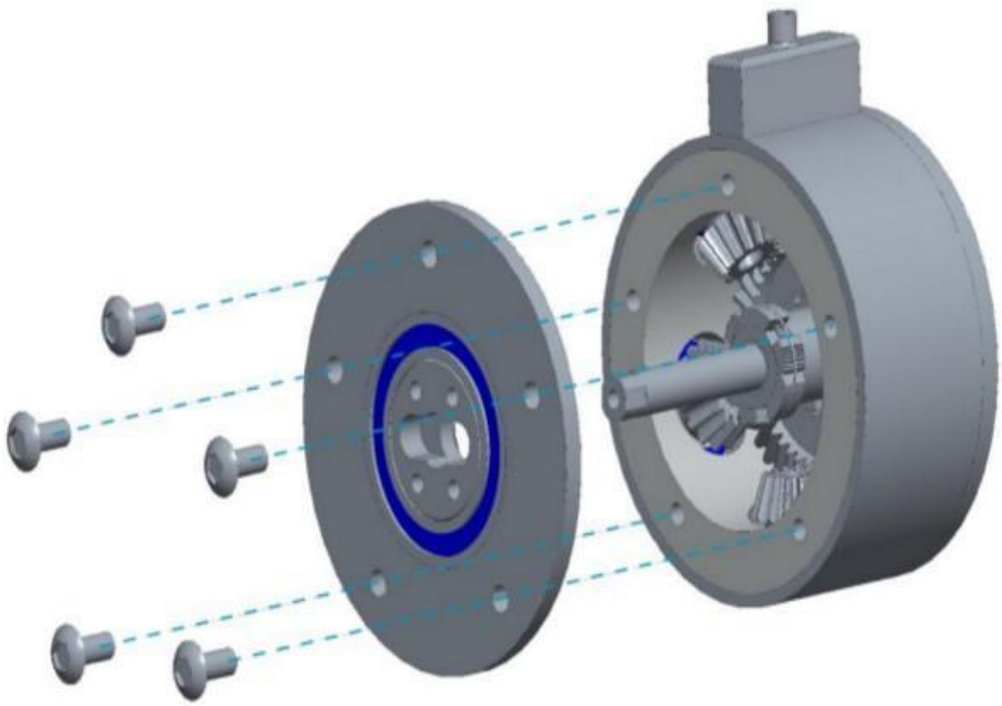

Figure 2: Reciprocating Lever Transmission CAD exploded view

Gordon Hansen has also requested, if possible, that the team try to find a way to alter the position of the bike rider. Previously, the seat and handlebars were at a position that causes the rider to lean forward, much like what is typical of a mountain bike. The optimum positioning for comfort would be an upright position, similar to that of a typical cruiser style bicycle. This new rider positioning was optimized by several adjustments such as a new handlebar stem, handlebars, and saddle or seat.

4. Project Goal/Objective

The primary objective of Team 8 is to develop the RLT into a fully functional transmission that is capable of safely and consistently delivering enough power to the ground to be on par with a traditional bicycle. Traditional bicycles can cause problems for the rider, especially when riding uphill. On a traditional bicycle, there are two dead spots within every full rotation pedal cycle, at the top and bottom of the rotation, where power is lost, and the rider is putting extra strain on their knees and joints. For this reason, the sponsor, Gordon Hansen, has patented the RLT design, in hopes to out-perform traditional bicycle power/torque/cadence values, and to improve the bike riding experience for the rider. The primary objective has been broken down into several subsections. The first and most important being the crank-arms, as those have caused the most issue. The second being the output shaft which transfers power from the crank arms to the sprocket. Last is finding a possible alternative to the ratchet and pawl mechanism that is currently only available from one vendor Triton Cycles in England.

An alternative to the ratchet and pawl mechanism is either to buy a similar design from a local bike shop which would allow us to modify it to accept the current ratchet and pawl mechanism. Another viable option after speaking with Jeremy in the machine shop, is to draw up and build identical pieces of the ones we need. Lastly, we can outsource the production of a similar design to online metal workers or a specialized bike manufacturer in California. Currently, the purchasing of the similar device or making the piece in house at the machine shop are being looked into. The outsourcing would take much longer and be a lot more expensive.

To achieve the goals previously stated, the new designs must incorporate up to 12” crank arms that reciprocate in arcs no greater than 100 degrees. The new design should improve the comfortability of uphill riding. Using the test rig to provide performance data of the bicycle is another important objective. Another goal is to test the RLT when finished. To do so a test rig will provide data on the power output, which will be able to give a good estimate of how much power is needed to ride uphill. The second objective is to include the new drivetrain in a bicycle frame that includes cargo-mounting stations that can be used for shopping errands and daily commuting in cities with hills. This bicycle design should fit in a standard shipping box with the dimensions of 26”x26”x10” when disassembled, in order to save on shipping costs.

5. Methodology

The project has several primary tasks that must be completed by the end of the semester. The HANSCycle must be in working order as well as tested so that its data may be compared to that of a traditional bicycle. Team 8 has designed, fabricated, and installed several components so that the HANSCycle would properly work.

The first of which is newly designed crank arms. These crank arms are constructed with steel in order to increase strength over the prior design, which sheared under stress. This shear stress was caused from operation and can be attributed to an aluminum design paired with misalignment of mounting holes. Only two of the four holes could be used which caused additional stress on the two aluminum keys which failed. The new crank arms were designed in Pro-Engineer by Team 8 in a way that pairs properly to the RLT. This new design has properly aligned holes which will increase robustness in unison with an all steel design. The steel used in fabrication was chosen by Team 8 to be Chromoly Steel or AISI4130. This steel is commonly used in bike construction due to its large increase in strength over a mild steel or aluminum. It is a steel alloy which implements two main impurities, chromium and molybdenum. This alloying procedure increases the strength but maintains weldability. This is important since the crank arms will receive most of the force supplied by the rider. The material for the crank arms was ordered from a third party and the alloying process has already been done for Team 8. After acquiring the material and finalizing the design, the FAMU/FSU machine shop will be utilized. The machinist will use Team 8's CAD model to fabricate the crank arm bases in the CNC machine. After the team receives the crank arm bases, a section of square tube Chromoly will be welded to the base in order to reduce weight and machining time that would be required if a one piece crank arm was implemented. Then a drill press will be used to drill and tap the hole required to accept the pedals.

In addition the crank arm, new needle bearings must be put into the RLT to regain functionality. The needle bearings previously used were sufficiently robust, however they failed due to improper alignment of the RLT shaft. The previous needle bearings were removed by hand since they were severely damaged. New needle bearing have been ordered to replace the previous ones and will be pressed into place using a press. Once in place they will allow for the shaft to spin in place with minimal internal friction.

Another key component that must be machined and implemented is a new shaft to go inside of the RLT. The previous RLT shaft was misaligned which caused extensive damage to the needle bearings and additional wear and tear on the ratchet and pawl design. Team 8 made a slight adjustment to the previous RLT output shaft in Pro-Engineer. The RLT design constrains the output shaft to the same dimensions within the system since that is all that will fit, however a more robust design was included for the locking mechanism. Previously a locking bolt was screwed into the end of the shaft. This was accomplished by drilling and tapping the end of the already narrow shaft. Team 8's design uses a locking nut instead. This is done by extending the shaft slightly and using a die to thread the outside of the shaft at the end. This allows for a nut to be put on in order to lock the system together, while still allowing for removability and an increase in strength.

After all other components are sourced and machined it must be reassembled. Team 8 will accomplish this using common tools such as drills and the appropriate bits. The bolts will all be replaced with a stronger Grade 8 bolt. This will be important for the longevity of the HANSCycle since there is large amounts of concentrated forces on the system and many of the components are small due to size and weight restrictions. Previous bolts used by Team 20 were sheared off or stripped out due to lower quality steel pared with misalignment of holes and the shaft.

6. Progress

Team 8 inherited the Hans cycle in the Fall semester of 2016. The team was initially under the impression that the RLT was in much better condition than they found it. Because the main focus of the sponsor, Gordon Hansen, was getting data comparisons, the team's original plan for the semester was to test the HANSCycle and get results to compare and analyze with a traditional bike. However, the team soon learned that the bicycle was not in working condition. The team's project plans quickly changed and they decided to focus on fixing and replacing the faulty parts. With the new plan in mind, Team 8 was able to make good progress. The broken or malfunctioning parts included the crank arms, multiple bolts, the ratchet and pawl, the output shaft, and bearings. The first focus was on the crank arms. The biggest issue with the old crank arms was that the bearing holes did not align with their corresponding holes on the RLT. This caused only two of the four bearings to be able to be fastened, which caused increased, un-for-seen torque to be put onto the secured bearings, resulting in the shearing of the crank arm keys.

The team tried various ways to resolve the issue, including machining new aligning holes, and redesigning the crank arms entirely. The team also machined holes in the crank arms at at 12, 10.5, and 9 inches, to be able to test various lengths and find the optimum crank arm design. Testing at these different lengths will allow the team to determine which produced the most power, was the most ergonomic (i.e. what length was the most comfortable), and didn't cause any collisions with the ground or bicycle wheels. After determining that the modified crank arms would no longer be an option, Team 8 decided to redesign and use alternative ideas for the crank arms. Using Pro-Engineer, the crank arms were redesigned to be made out of 4130 steel and utilized a more basic design in order to speed up manufacturing. To ensure that crank arms were capable of withstanding the load, an FEA was run with a 250 lbf applied perpendicular to the pedal position. This can be seen in detail later in the analysis section. A CAD model as well as the multiple stages of the CNC process can be seen in the figures below.

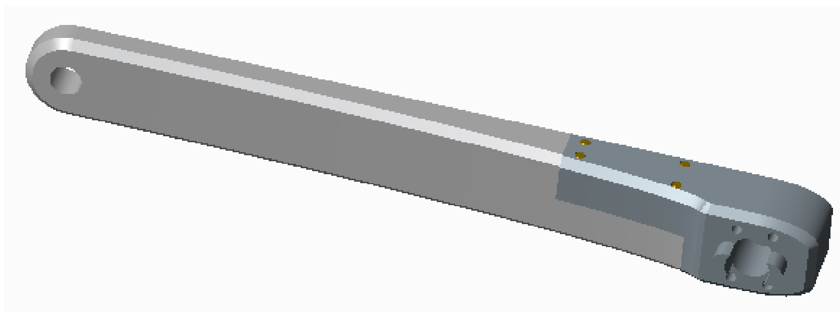

Figure 3: Crank arm design 1

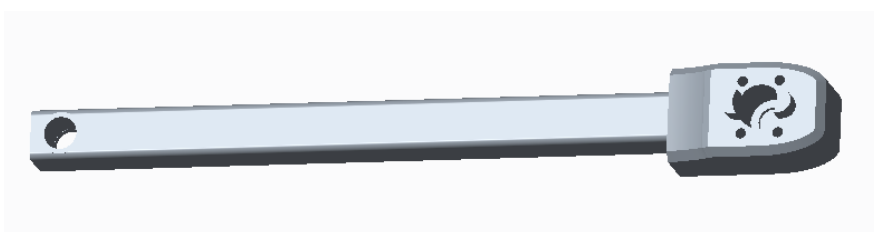

Figure 4. Crank arm design 2

The output shaft was another component that required a redesign. The original output shaft was made by pressing a case hardened shaft into a mild steel outer component. However, in doing so the shaft had been placed and welded off center, which caused the shaft to spin off axis. The new shaft design involves a similar design because of the size constraints within the RLT, however the new shaft uses a cases hardened inner shaft and a 4130 steel outer shaft. The inner shaft has also been extended by 12mm to allow for threads on the outside instead of the inside like in the previous design. This allows for a smaller displacement when running FEA because there is no longer a small wall thickness between the output shaft and the chain ring.

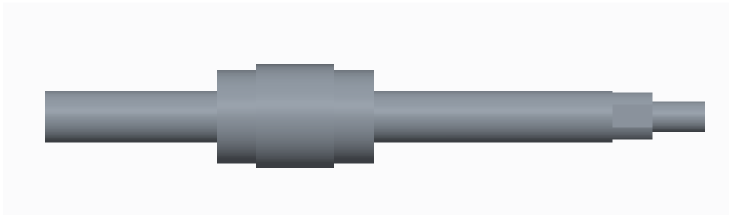

Figure 5. New shaft design

After redesigning, a few of the broken parts. The materials were ordered so that the machining of the parts can begin.

7. Finite Element Analysis (FEA)

Prior to having the new designs sent to the machine shop to be made, finite element analysis was run on both the new crank arm design and the output shaft. The crank arm design had an applied load of 250 lbf at the point where one’s foot would make contact with the pedal. Looking at the figure below, one can see that the displacement is estimated at about 3.25 mm. While this is good, it is also relevant to note that the information is based on mild steel because Pro/Engineer does not have the properties of 4130 steel. The tensile strength of 4130 is almost double that of mild steel so the deflection would be lower than estimated.

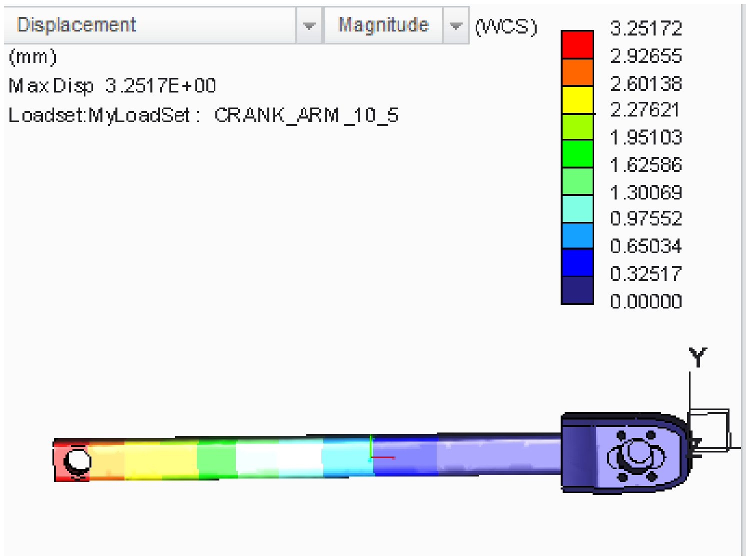

Figure 6: FEA of Crank Arm

The output shaft was also put under FEA. The output shaft was constrained in four locations like how it would be in the transmission. After apply the 250 lbf to the point where the chain would pull on the shaft the displacement was negligible. With both the FEA run on the output shaft and the new crank arms it was deemed to be capable to withstand the necessary applications and work orders were submitted to the machine shop.

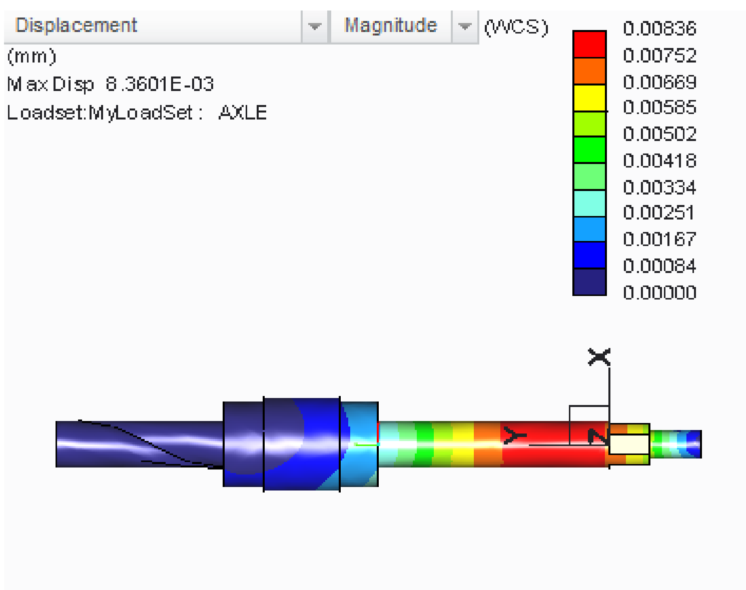

Figure 7: FEA of Output Shaft

8. Fall Semester Conclusion

Team 8 plans for the fall semester were met with a few major challenges. For one, in addition to the parts that were already broken, new parts began to break. Socket head screws, needle bearings, and locknuts began to malfunction, and required replacement. Almost every crucial component of the RLT broke in some fashion. Due to the breaking of numerous parts, Team 8 was not able to test the HANSCycle. Even when initial testing took place, more pieces broke so the testing was inconclusive. Team 8 had to purchase even more new parts to replace the broken ones which continued to push back the schedule. This put the team behind in the schedule to have the new crank arms built by the end of the fall semester.

Another major issue was the procurement of materials. After ordering the metal for the new crank arms, Team 8 was waited on the metal order to arrive. After 3 weeks of waiting, one of the team members luckily stumbled upon the metal that was ordered, and the team found that they had simply not been notified when the shipment was received. Prior to this mishap, team 8 was on schedule to get the new designed crank arms machined. However, due to the 3 week set back, the new crank arms were not able to be machined by the end of the fall semester, as planned.

In addition to the metal being lost, the team found that the only vendor of a crucial part, the replacement ratchet and pawl, was not accepting the payments from the school. There were multiple attempts to purchase the parts, but none of them were successful. This is yet another issue to cause a big setback on the building and testing of the HANSCycle prototype. Possible solutions include finding an alternative to the ratchet and pawl system, or ordering custom parts.

In conclusion, Team 8 experienced multiple setbacks, including broken parts as well as procurement issues. For this reason, the team was unable to fulfill fall semesters goals of building new cranks arms. The spring semester seemed promising, and the team did not expect any delays or setbacks.

9. Spring Schedule

Team 8 has been working on the HANSCycle and RLT since the project was assigned. All deliverables have been turned in punctually, and critiques have been taken into account, in an effort to improve various aspects of the project itself as well as the deliverables. When the semester is over, in May, Team 8 hopes to have successfully completed and fulfilled all goals for the

HANSCycle project. Firstly, a working prototype is expected to be completed by mid-February. The team has been slightly behind the original schedule because of issues with procurement of parts and materials. Once a prototype is completed, testing will be done to compare various crank arm lengths, in order to determine the most efficient length and arc. Once a length has been chosen, the HANSCycle will be tested on the Kinetic Road Machine, to obtain values for torque, power, cadence and speed. These values will then be compared with a traditional bicycle, also tested on the Kinetic Road Machine, to see the differences.

Using the comparison of test values, the team will decide what next steps to be taken. If the HANSCycle values are close to, or greater than, the traditional bicycle's, the team will focus on ergonomics of the bicycle. This would include changing the user's position on the bike by possibly moving the seat, handle bars, or even the RLT itself, without having a large impact on the test values. However, if the HANSCycle values are much lower than the traditional bicycle's, the team will have to reevaluate its design and approach. This could include changing the crank arm length or design, altering the RLT gears and inner components, or trying different materials. Various parts of the HANSCycle would then have to be reconstructed, and testing would have to be repeated, in order to attempt to improve the overall function and test values of the HANSCycle. When the semester has ended, the team hoped to have a successful HANSCycle, functioning as efficiently as a traditional bicycle.

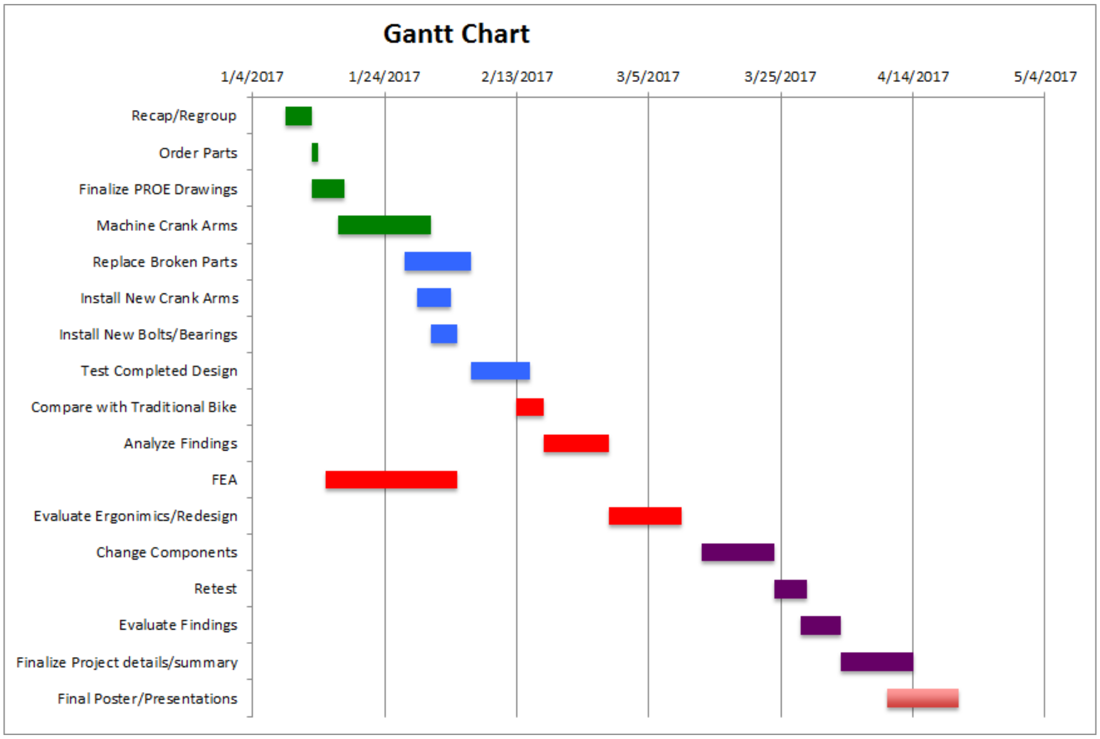

Figure 8: Gantt Chart

As can be seen in the Gantt Chart above in Figure 8, the team set up a rough schedule with flexible time limits for the spring semester. Similar to the fall semester, the team encountered various problems with certain materials failing. Ultimately those problems affected the schedule and the goals of the spring semester. Originally we expected to have tested and compared the results of the HANSCycle to a traditional bicycle by the early parts of the year. Due to those issues stated above we were not able to accomplish this goal. Luckily the schedule was able to be adjusted, and although we were not able to compare the two bicycles we did test the HANSCycle multiple times. The data results are shown below in table 2 and 3.

10. Spring Failed Components

During the spring semester, a few other components broke. These parts include bearings, socket screws and most importantly the inner shaft. The shaft was the most focused issue during the spring semester, and the team went through multiple iterations of design. The problem was that the shaft was not able to withstand the torque generated by the HANSCycle. The shaft required redesign of the mating surface, and the team found that a hexagonal mating surface was the strongest and best option, as well as increasing material strength and shaft size by nearly 40%.

11. Spring Newly Designed Components

A new shaft was design for the HANSCycle. The original shaft was too thin and not made of strong enough material, so it failed, as well as an original redesigned shaft. The final shaft design is made of 4340 300M alloy steel. The shaft is 40% larger in diameter, and the shaft-to-chainring adapter mating point is 50% larger, both parameters that greatly affect the strength of the shaft. Additionally, a hexagonal mating surface has also been incorporated, seen in Figure 9 below, which again adds strength to the shaft, especially considering the former square mating point.

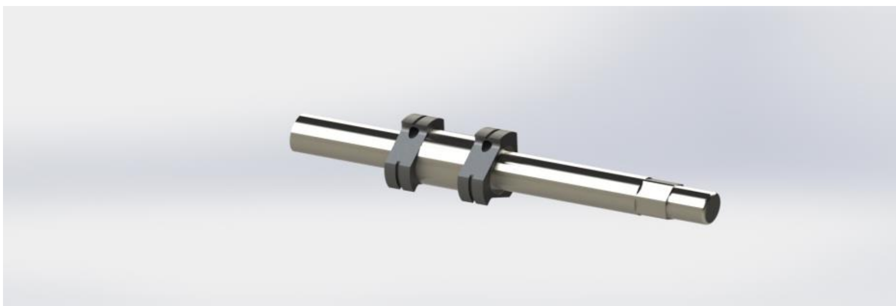

Figure 9: New shaft CAD model

In Figure 10 below, the original shaft and redesigned shaft can be seen and compared. The original shaft had an inner tap, while the redesigned shaft has an outer tap, as well as a hexagonal mating surface, both of which increase the shaft's strength.

Figure 10: Original shaft (left) redesigned shaft (right)

12. Budget

Continuing with the budget of $2,000 given to team 8 from the fall semester, more items were purchased. Below is a table with the updated purchases made by team 8. The purchases include new material for the shaft to improve the performance of the HANSCycle. Items to improve the ergonomics such as a new seat, handle bars, lights, and horn. The newest purchased was a flywheel to help improve the testing dynamics. Overall the budget left over is $625.72. The remaining funds may be used to purchase more materials to help the future group improve the HANSCycle.

Table 1: Budget/Expenses breakdown

#	Part	Vendor	Cost	Quantity	Subtotal
1	½ in. Hexagon Broach	McMaster.com	$241.89	1	$241.89
2	M12-1.75 Class 10 flange locknut	McMaster.com	$10.65	1	$10.65

3	⅞ in. diameter 3 ft. 8620 alloy steel rod	McMaster.com	$22.68	1	$22.68
4	14mm ID 18mm OD Oil-embedded sleeve bushings	McMaster.com	$1.75	4	$7.00
5	14mm ID 16mm OD Dry-running sleeve bearing with steel shell	McMaster.com	$4.23	2	$8.46
6	New OEM Components (handlebars, kickstand, seat, lights)	University Cycles	-	6	$179.94
7	Kinetic Pro Flywheel	Walmart	$89.00	1	$89.00
				Total	**$739.56**
				Remaining Budget	**$625.72**

13. Test Data

Prior to the spring semester the bike was tested and it completely failed. After fixing most parts, the bike was tested again and the data is shown below in table 2.

Table 2: Original RLT Test Data

	RLT	Traditional Bicycle
Average Power	22 W	33 W
Average Speed	6.0 mph	6.0 mph
Average Cadence	18 rpm	32 rpm

This data is skewed because the bike was not fully operational. Therefore the data is inconclusive. However after the newly designed shaft was installed on the HANSCycle, more test were taken and the results of these tests are presented in the following table. These values show a considerable increase in power speed and cadence. One can see in the table below that the new shaft design and material made a difference in the performance of the HANSCycle.

Table 3: Most recent RLT test data

	RLT	Traditional Bicycle
Average Power	105 W	100 W
Average Speed	13 mph	15 mph
Average Cadence	50 rpm	-

The table above shows major improvement of the RLT. The team found that comparing cadence speed between the HANSCycle and a traditional bicycle to be difficult, as the cadence of the RLT does not consider the fact that each pedal movement is a fourth of one rotation. However, from these results, it appears that the RLT is producing slightly more power than a traditional bicycle. Further testing of both bicycles will be necessary in order to verify the findings.

14. Comparison to Traditional Bicycle

Team 8 has hopes of testing a traditional bicycle using the same testing constraints the HANSCycle was tested under. The results of both test would then be compared and used to further improve the HANSCycle. The HANSCycle was created to compete with the traditional bicycle market, therefore it is essential to compare the data. Due to unexpected issues as well as scheduling conflicts, Team 8 was not able to compare the results with the results of a traditional bicycle.

15. Future Plans/Recommendations

Team 8 has various recommendations for the next steps of the HANSCycle. One of these ideas is to enlarge the entire RLT system. Increasing the RLT size involves increasing bevel gear size, shaft size, and will also allow for the use of an off-the-shelf sprag clutch. The sprag clutch, as well as the larger bevel gear and shaft, will aid the RLT in supporting more torque, a higher load, and will increase outputs and efficiency. Another option would be to keep the RLT at its current size, and order a custom ratchet and pawl design, made of stronger material in order to function perfectly for the HANSCycle. Increasing the gear ratio is another option that would improve the performance of the RLT and HANSCycle. Other than the function of the bicycle, adding a basket or storage/cargo compartment onto the HANSCycle would be a bonus accessory that would make a difference in its daily use and function.

16. Conclusion

Team 8 did a lot of work on the HANSCycle project over the past two semesters. The project began by identifying the points and parts of failure from last year's senior design team, then reverse engineering. Unfortunately, after fixing faulty parts, other bicycle components would fail and again push back the team's schedule and aims to test the HANSCycle. Increasing material strength of various components was necessary, as well as some redesigning of parts throughout the project, including the crank arms and inner shaft. Team 8's original schedule was delayed and changed, due to failed components throughout the two semesters. After various failures and struggles, team 8 managed to complete the design of the RLT and test it, to compare with a traditional bicycle. Test results found that the RLT power increased dramatically, and even seems to output more power than traditional bicycles. Further testing and design iterations would be beneficial, to find the optimum design and parameters for the HANSCycle. The sponsor, Gordon Hansen plans to continue project work on the HANSCycle, and is confident in its design and future success.

The Development of the HANSCycle RLT

Design for Manufacturing/Reliability/Economic Report

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Dr. Chiang Shih

1. Abstract

Team 8 is dedicated to developing a working HANSCycle, which implements the Reciprocating Lever Transmission (RLT) designed by Gordon Hansen. The goal of the RLT is to improve upon a few aspects of the traditional bicycle. These include two ‘dead spots’ at the top and bottom of a normal pedal rotation, as well as alleviating joint damage to the user from the ‘dead spots’. If successful, the HANSCycle will be both efficient and ergonomically comfortable for the user. Once a working prototype was developed, the team tested it and compared values such as torque, cadence, work, and speed, with values of a traditional bicycle. Initial testing has been promising, as the data suggests favorable power transfer from the user to the road. However, the current size constraints of the initial prototype have led to premature failures. This has been primarily due to the high levels of torque transferred through the RLT, which has caused several components to shear, including most recently, the output shaft. The torque produced by the RLT is greater than a traditional bicycle because of the increased crank-arm length. This project strives to prove that the Reciprocating Lever Transmission can perform as well as or even better than a traditional bicycle, while also causing less stress and damage to the rider’s joints.

2. Introduction

While traditional bicycles have been redesigned and streamlined, their overall function and design has not been altered much. This project aimed to change that. The Reciprocating Lever Transmission (RLT) aimed to improve the function of the traditional bicycle. Traditional bicycles are known to have two 'dead spots' at the top and bottom of a full pedal rotation, which causes stress and joint damage to the ride, specifically when traveling uphill. The RLT design uses dependent motion to ease stress on joints, while increasing power and torque. Using clipped-in shoes, a rider is able to create power on both the upstroke and down stroke, maximizing energy and efficiency. This report aims at breaking down various design aspects, and further explaining the thought process and goals throughout each aspect.

3. Design for Manufacturing

When designing a product, its ability to be manufactured easily and efficiently is a very important parameter. This requires the design, no matter how intricate, to be rather simple to machine, as well as be made of accessible materials, realistic processes, and adaptability to market demands. With this said, the HANSCycle was designed with these aspects in mind.

One would likely begin the manufacturing of the HANSCycle by starting with the frame. The frame tubes must measure, cut and notched individually, before being welded together. After the frame is assembled the components that need to be fabricated must come next. The fabricated components of the RLT include the crank arms, the chainring adapter, and the output shaft. The crank arms require CNC machining, cutting and notching, tapping and finally welding. The chainring adapter is first cut using the water jet, followed by milling to proper dimensions to allow for the sprocket to mate and finally the hexagonal broach is pressed to create the hexagon mating surface. The last fabricated component is the output shaft which is first turned to the proper dimensions on the lathe. Next it is heat treated to the desired case hardening specs and finally the drivers checked to make sure proper fitment exists after the change in size of the shaft due to heat treating. Next is the RLT itself, consisting of bevel gears, inner/outer housing, output shaft, and bearings. A large bevel gear should be assembled into the outer housing, and be secure. The five small bevel gears have exact holes in which to assemble each with a bearing. Once these have been assembled, the crank arm should be next. The crank arms will have brass oil-embedded bushings pressed into them. This is in what the output shaft will be held by and rotate within. The output shaft will also need the drivers for the ratchet and pawl to be welded and installed in opposite directions. This is necessary in order to allow for the RLT movement in the appropriate direction. Then the large bevel gear and housing can be slid onto the output shaft, and the output shaft can move through the crank arm bushings. The other side of the outer housing, containing the five smaller bevel gears should be placed on top of the crank arm set up, ensuring that the seams are flush. Then the other crank arm can be attached to the shaft through its bushing and secured with the grade 8 cap head screws. The chain ring adapter should then be put onto the shaft so that the hexagon pattern lines up properly. After which the grade 8 locking flange nut should be properly tightened to ensure it will not come loose.

When the frame and RLT have been assembled, the RLT must then be secured to the frame. There are three mounting tabs in double shear that are welded to the bike frame. This is to ensure that the RLT is lined up properly and secured. The RLT can then be bolted to the frame. The remaining off-the-shelf components, including the gears, brakes, handlebars, and seat, can be installed.

Overall the design of the RLT is more complicated than a traditional bicycle. However, due to the complexity of the reciprocating motion and the size constraints on the design there are very few ways to simplify the device. Due to the complexity of the RLT and its components, some of the manufacturing took a long time and several different tools needed to be bought or made. Since this is the case, if and when this design moves towards production, a large amount would need to be made to keep costs low and to justify the many one off components.

4. Design For Reliability

Bicycles can, and often do offer years of service. They are fairly low maintenance mechanisms that are designed to last. In order for the HANSCycle to be a feasible replacement for the traditional commuter style bicycle it must be designed and manufactured in a robust manner. This mean that there should be sufficient factors of safety, and good design practices throughout. The HANSCycle was designed to be an everyday commuter with the ability to produce more torque than is produced in traditional bicycle. Fundamental engineering practices and modern computer aided design software allowed Team 8 to produce robust components that should last for years.

4.1 Crank Arms

The crank arms on the HANSCycle went several iterations before the final set used in the prototype was decided upon. Unlike the previous design, they are constructed of 1018 and 4130 steel which is much stronger than the aluminum used before. The crank arms were designed to be more visually appealing, cheaper, and less likely to fail then the original crank arms. The new crank arms being made of steel lowered the cost substantially while retaining the required strength. The new crank arms use a 1018 steel block that was cut using a CNC to match the required mating features of the RLT. A piece of ¾ in. 4130 square tubing was then cut to the desired length and welded into a slot within the steel block. Lastly, a notch was cut to house the shaft which was tapped to allow for the pedals to thread in. The new crank arms can be seen in the picture on the right in the figure above. When simulated in pro-engineer, a reasonable load would only cause a deflection of 3.2517 mm with no chance of failure. The keys and holes in the steel version also proved necessary, as the aluminum versions failed prematurely due to the stress applied by the riders. The strength of the steel keys and holes held up well to the task of powering the HANSCycle at full speed.

Figure 11: Completed all steel crank arms

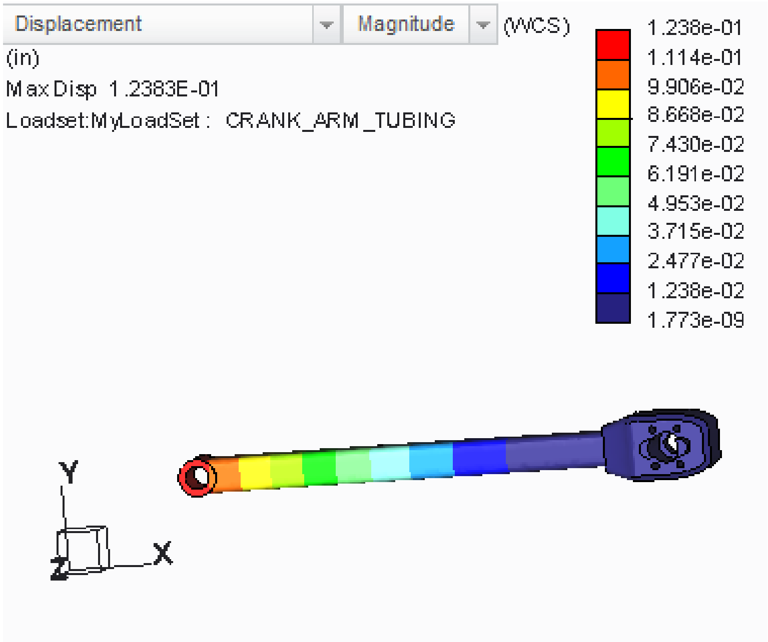

Figure 12: Crank arm Failure Analysis and finalized crank arms

4.2 Output Shaft

Another highly stressed component is the output shaft which is the core of the RLT. This shaft provides the link between input force into crank arms and the chain ring adapter which powers the chain ring, chain, thus back wheel of the HANSCycle. This component has failed before due to the size constraints of the RLT. The most recent iteration is an all steel design which will be 14mm in diameter rather than the 10mm shaft used before. This additional size will allow the will allow for a more robust design. The new output shaft has also been made out of 8620 alloy steel and has been case hardened. The heat treatment process will allow the steel to have a hard outer layer and a softer middle. This is necessary to ensure that the shaft will twist many times before failure but allows for the outside to spin freely in the bushings. The hardened surface also allows for the mating point of the shaft and the chainring adapter to remain constant and lowers the chance of any rounding on the hexagon points.

Figure 13: Original shaft vs new shaft (left), before and after heat treatment (middle), before and after the heat treated shaft was cleaned up (right).

In the first picture of the figures above one can see the size difference between the original output shaft and the new larger and more robust one. The middle picture shows the output shaft before being heat treated on the left and after on the right. The 8620 alloy steel was heated to 830°C and then water quenched. After the shaft was quenched it was put into the furnace again at 200°C to be tempered for 2 hours. The output shaft on the right in the second picture shows how the surface finish looked after this process. The picture on the right shows the difference in surface finish after the surface had been cleaned.

Figure 14: On the left is the furnace that was used and on the right is the power supply with the temperatures of each zone and the furnace.

4.3 Bicycle Frame

The frame of the HANSCycle is constructed of 4130 alloy steel tubing. This strong steel is both light and tough and welds well. The completed design merely weighs 6 pounds and has a factor of safety of about 1.9 when a load of 250 pounds were on the HANSCycle and it were to drop 3 feet. This was done as a worst case scenario where the rider was 250 pounds and the bicycle experience a sudden fall from 3 feet which is not recommended and very likely. Based on the FEA, the frame should provide the rider a lifetime of enjoyment when properly cared for.

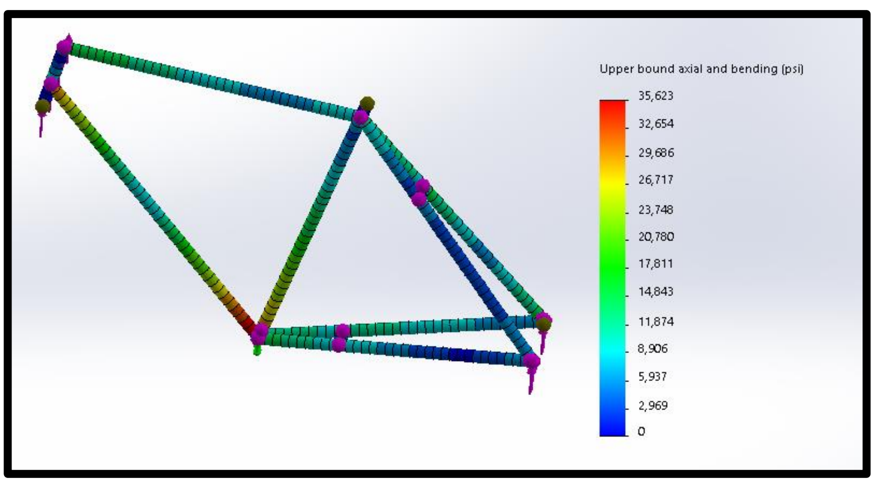

Figure 15: Frame FEA

5. Design For Economy

The total cost of the HANSCycle prototype can be seen below in Table ####. The final cost for the components used in the final prototype are only $### which is well below the $2,000.00 budget allocated to Team 8. It should also be noted that the cost of both the components and the ram materials would significantly decrease if this bicycle were manufactured at a larger scale and manufacturing time would dramatically decrease which would help save money on production costs of a finalized production model. Although the production model was at a higher cost, the sponsor would like to have a low, middle and high end options for this product to sell. Team 20 decided to design a high end quality product. The use of high end products also played a role in the high cost of a finalized production. The high quality material was ordered from vendors like McMaster Carr, speedy metals and KHK gears. The final product (HANSCycle) is designed to be a commuter bicycle, for everyday use in a city. As a result this product fits a variety of consumers. It will be able to be broken down and put inside a 26” x 26” x 10” to be able to ship. The HANSCycle is a unique product because it is the first of its kind. Therefore there is no market to compare pricing for this style of bicycle. With the high end products and the uniqueness of the HANSCycle, the average cost could be anywhere between $2,000 and $4,000.

Table 4: Procurements

#	Part	Vendor	Cost	Quantity	Subtotal
1	**Needle Bearing**	**McMaster.com**	**$16.65**	**3**	**$49.95**
2	**Rotary Shaft**	**McMaster.com**	**$8.20**	**2**	**$16.40**
3	**Socket Head Screws**	**McMaster.com**	**$9.05**	**1**	**$9.05**
4	**Locknuts**	**McMaster.com**	**$9.03**	**1**	**$9.03**
5	**½ in. Hexagon Broach**	**McMaster.com**	**$241.89**	**1**	**$241.89**
6	**M12-1.75 Class 10 flange locknut**	**McMaster.com**	**$10.65**	**1**	**$10.65**
7	**⅞ in. diameter 3 ft. 8620 alloy steel rod**	**McMaster.com**	**$22.68**	**1**	**$22.68**
8	**14mm ID 18mm OD Oil-embedded sleeve bearing**	**McMaster.com**	**$1.75**	**4**	**$7.00**

9	**14mm ID 16mm OD Dry-running sleeve bearing with steel shell**	**McMaster.com**	**$4.23**	**2**	**$8.46**
10	**Oneway Bearing with Keyway**	**VXB bearings.com**	**$24.95**	**5**	**$49.90**
11	**rachet and pawl**	**Triton cycles (UK)**	**$90.00**	**2**	**$180.00**
12	**square tube**	**speedy metals**	**$5.95**	**1**	**$5.95**
13	**round bar (shaft)**	**speedy metals**	**$6.89**	**1**	**$6.89**
14	**steel plate**	**speedy metals**	**$29.53**	**1**	**$29.53**
15	**square bar**	**speedy metals**	**$21.16**	**1**	**$21.16**
16	**socket screws**	**Mcmaster.com**	**$9.82**	**1**	**$9.82**
17	**SUB1.5-4515 45-tooth bevel gear**	**KHKgears.com**	**$84.63**	**2**	**$181.14**
18	**KSUB1.5-1545**	**KHKgears.com**	**$34.42**	**1**	**$34.42**
				Total	**$1105.34**
				Remaining Budget	**$894.66**

The Development of the HANSCycle RLT

Operational Manual

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1. Abstract

Team 8 was tasked with the testing and optimization of the current HANSCycle prototype. This prototype utilizes the reciprocating lever transmission invented and patented by our project sponsor Gordon Hanson. The HANSCycle's main purpose is to be a viable alternative to current commuter style bicycles that have several drawbacks including lack of torque and the potential for knee damage. Due to the 360 degree revolution, the crank arms on a traditional bicycle are limited due to ground clearance. The 100 degree arc length of the RLT allows for longer crank arms, thus producing more torque available for strenuous rides up steep grades. The other benefit the the RLT design is that you avoid the two "dead" spots present in a traditional bicycle. These "dead" spots are located at the top and bottom of the pedal motion were no useful work can be produced and causes unnecessary stress on the rider's knees, which is believed to cause joint issues over time.

2. Introduction

Sponsor Gordon Hansen patented an reciprocating lever transmission (RLT) transmission with the goal of using the RLT to enhance the traditional bicycle by creating the HANSCycle. The HANSCycle is a bicycle that is constructed with the Patented RLT. The main difference between a traditional bicycle and the HANSCycle is the pedal motion. A traditional bicycle uses a 360° rotational crank motion whereas the HANSCycle uses a reciprocating motion with arc no greater than 100°. The 360° on the traditional bicycle has two dead spots at the top and bottom of the pedal motion which no torque nor power. In addition to those dead spots, the crank motion on the traditional bicycle causing pain and stress on the knee joints of riders especially when riding uphill. The RLT is designed to combat these issues by easing stress on the knee joints while also consistently providing more power and torque. As a result riding uphill will be easier for the common rider.

3. Problem Statement

"A traditional bicycle is difficult to ride up hill due to its limited torque output and can also be damaging to a rider's joints."

Team 8 has been tasked with developing a working HANSCycle implementing the Reciprocating Lever Transmission (RLT). The goal of this design is to improve upon a few aspects of the traditional bicycle, including two 'dead spots' at the top and bottom of a normal pedal rotation, as well as alleviating joint damage to the user from these dead spots. If successful, the HANSCycle will be more power efficient and ergonomically comfortable for the user. Once a working prototype has been developed, the team must test it and compare values such as torque, cadence, work, and speed, with values of a Traditional Bicycle. This project hopes to prove that a reciprocating lever transmission on bicycle can obtain similar results in performance compared to a traditional bicycle, while also causing less stress and damage to the rider's joints.

4. Project Scope

Gordon Hansen, the HANSCycle sponsor, believes his redesign of the traditional bicycle will lead to a new age of bicycling. The goal of the Reciprocating Lever Transmission is to maximize efficiency and ease stress on the user's joints due to the "dead spots" in a traditional bikes transmission. These "dead spots" can cause joint harm and are unconducive to an efficient ascent uphill. He believes that the short crank arms on traditional bikes require more work from the bicycle rider, and has therefore patented his design. The RLT incorporates larger crank arms that can produce more torque and travel in an arc no greater than 100 degrees, which avoids the dead spots.

5. How it works

5.1 RLT

The reciprocating lever transmission or RLT works by using a ratchet and pawl system to engage the output shaft in one direction, while allowing the teeth to slip in another. This is done by the use of two main 45 tooth bevel gears that are situated to the outer edge of the RLT. The bevel gears are driven by pressing down on the pedal which applied torque to the output shaft. This large bevel gear is in mesh with five bevel gears that are mounted within the RLT which in turn is in mesh with another bevel gear on the other side. This allows for dependent motion, meaning as one crank arm moves down, the other crank arm must move up. This is repeated after a 90 to 100 degree cycle. Mounted to the center axle or output shaft are the two ratchet and pawl mechanisms. These systems are mounted in opposite directions so that while one is engaged, the other is allowed to freely slip. That means as the crank arm moves the output shaft is always powered in the forward direction to produce usable power.

5.2 Brakes

The HANSCycle uses off the shelf hydraulic brakes which are composed of several components. The brake discs are dependently attached to the front and rear wheels of the HANSCycle. This means that if the angular velocity of the disc decreases so does the wheels which in turn slows down the HANSCycle. They are slowed by means of friction from the brake pads which are pressed onto the disc due to the master cylinder driving a non-compressible brake fluid within the sealed brake lines to the pads. The user creates this pressure simply by pulling on the brake levers on both the left and right handlebars. Applying the left brake lever will engage the front brakes, the right will engage the rear brakes, while squeezing both levers will apply force to the front and rear brakes.

5.3 S&S Couplings

S&S Machine Bicycle Torque Couplings are used within the bicycle frame in order for the frame to be taken apart to fit into travel cases or for storage. They are designed using a high quality stainless steel and lock together using two primary systems. Internally the coupling have a system of lugs that lock in together and the external coupling housing incorporates a threaded screw on system that further locks it together and seals the unit together.

6. How To Use It

The RLT HANSCycle is used in a very similar way the traditional bike is used. The main difference between the RLT HANSCycle would be the pedal motion. Instead of a 360° rotational motion, the HANSCycle works on a 90° to 100° reciprocating motion. As the rider pedals downward on one crank arm, the other crank arm is driven upward.

To use it the rider will wear the proper safety equipment existing of helmet, knee and elbow pads and any other necessary equipment. Once the rider in the seated position the rider is ready to begin powering the HANSCycle.

To power the HANSCycle the rider will pedal the crank arms in a reciprocating motion. As one crank arm moves downward the other one will move upwards. The cycle will begin moving forward just as a traditional bicycle would. Once the first pedal gets the bottom position, apply a downward force to the other pedal so that it goes down and the bottom pedal is driven upward. This process will be repeated at the desired cadence to increase or decrease speed.

The handle bars are used to steer the HANSCycle just like a traditional bicycle. This can be accomplished by simply pushing on one side of the handle bars with one hand, while the other hand pulls towards the body.

There are also hydraulic brakes on the handlebars that are available to slow or bring the HANSCycle to a complete stop. The brake lever located on the left handle is used to engage the front brake, while the right brake lever can be used to engage the rear brake. Both can be used at the same time to maximize the braking power, and it should be noted that engaging the front brake alone could cause the HANSCycle to lose control do to the front wheel locking up at high speeds.

The HANSCycle does not roll backwards so additional steps must be taken to suddenly change directions. First the rider may attempt to make a sharp turn by pushing on one side of the handle bars, while pulling on the opposite side. To move backwards the rider must lift the cycle and place it in the designated direction or lift the rear tire off the ground while moving it backwards.

The S&S couplings can be used to take apart the HANSCycle frame for easy storage or travel. To take the couplings apart the S&S coupler tool can be used to unscrew the threaded portion of the coupling and then can be further disassembled by using your hands.

The HANSCycle is also equipped with a Shimano 11 speed internal gear rear hub. Gear changes on the HANSCycle are just like on a normal multi speed bicycle. The gear shifter located on the right side of the handlebar is used to shift through gears 1-11. Lower gears will allow for easier pedaling in high demand situations such as riding up steep grades, while the higher gears will allow for faster top speeds in low torque applications.

One desired feature was the ability to easily break down and store the HANSCycle for travel. To minimize the size of the HANSCycle, a few steps is required. First deflate the front and rear tires. This will decrease the footprint of them about 1.5 inches each. Next the crank arms can be removed and reinstalled backwards. This will keep them in place, but they will store neatly within the rear triangle of the frame. The S&S couplings can then be disconnected in the two frame locations. This will allow for the front and rear half of the HANSCycle to be separated or stacked to minimize storage space. Lastly, the front wheel can be easily removed to further breakdown the HANSCycle and minimize storage space. Figure 1 below further illustrates how the HANSCycle is used.

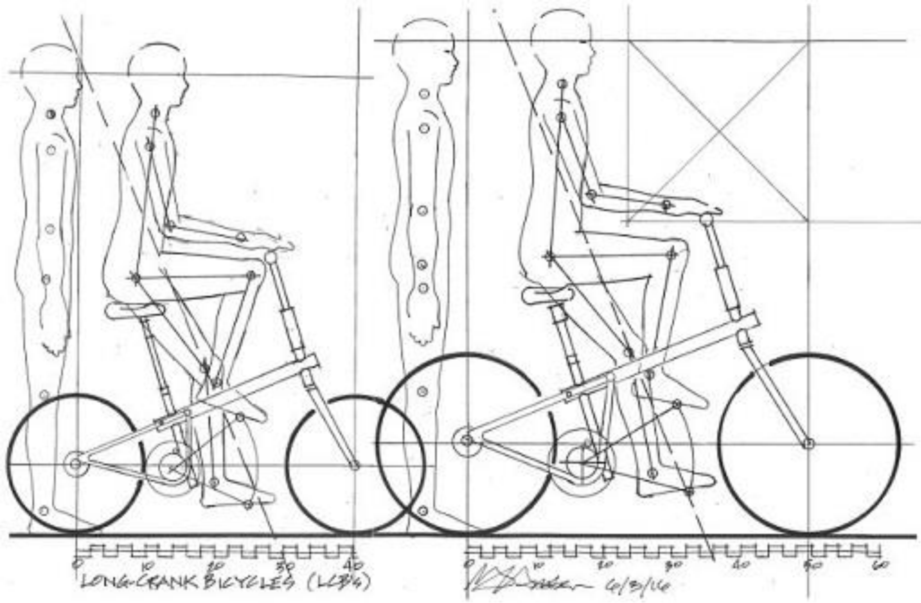

Figure 16: HANSCycle initial drawing

7. Risks

Riding a bicycle always has some risks associated with it. As with any bicycle, the rider should be of appropriate size and age. They must be able to reach the ground, pedals, and handlebars comfortably. It is also highly recommended that the rider wear a properly sized bicycle helmet to protect the rider in the event of a collision or fall. It is also recommended that the rider wear closed toe shoes so that they do not hurt or injure their feet on the pedals or ground. Although the HANSCycle comes equipped with rear and forward facing running lights, the rider must take great car while riding at night or in dimly lit areas.

Even Though the HANSCycle is constructed of strong and reliable materials, there is still possibility of the HANSCycle malfunctioning. There will be noise when riding the bike due to the grinding of the ratchet and pawl system. Some of the risks include: shaft shearing, bolts shearing, the gears on the bike can jam causing trouble pedaling. Also the seat positioning of the HANSCycle. To fix these issues, one must take apart the RLT to service each individual component.

8. Price/cost

Many of the components of the HANSCycle failed. Therefore, many of the components needed to be replaced. New metal for the crank arms, new bolts and metal for the shaft has been on the list of items for purchase. Originally Team 8 had a budget of $2,000 to spend on anything that would be an asset to building a working prototype. Below is the list of materials that has been purchased by team 8 this year. (note: shipping and handling prices are not listed)

Table 5: Procurements

#	Part	Vendor	Cost	Quantity	Subtotal
1	**Needle Bearing**	**McMaster.com**	**$16.65**	**3**	**$49.95**
2	**Rotary Shaft**	**McMaster.com**	**$8.20**	**2**	**$16.40**
3	**Socket Head Screws**	**McMaster.com**	**$9.05**	**1**	**$9.05**
4	**Locknuts**	**McMaster.com**	**$9.03**	**1**	**$9.03**
5	**½ in. Hexagon Broach**	**McMaster.com**	**$241.89**	**1**	**$241.89**
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7	**⅞ in. diameter 3 ft. 8620 alloy steel rod**	**McMaster.com**	**$22.68**	**1**	**$22.68**
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9	**14mm ID 16mm OD Dry-running sleeve bearing with steel shell**	**McMaster.com**	**$4.23**	**2**	**$8.46**
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12	**square tube**	**speedy metals**	**$5.95**	**1**	**$5.95**

13	**round bar (shaft)**	**speedy metals**	**$6.89**	**1**	**$6.89**
14	**steel plate**	**speedy metals**	**$29.53**	**1**	**$29.53**
15	**square bar**	**speedy metals**	**$21.16**	**1**	**$21.16**
16	**socket screws**	**Mcmaster.com**	**$9.82**	**1**	**$9.82**
17	**SUB1.5-4515 45-tooth bevel gear**	**KHKgears.com**	**$84.63**	**2**	**$181.14**
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				Total	**$1105.34**
				Remaining Budget	**$894.66**

9. Functional Analysis

The HANSCycle is composed of many individual parts, however the Prototype can be broken down into a few major components: The RLT, the frame, and OEM (Original Equipment Manufacturer) Parts.

9.1 RLT

The RLT, or Reciprocating Lever Transmission, can be seen below in Figure 2.

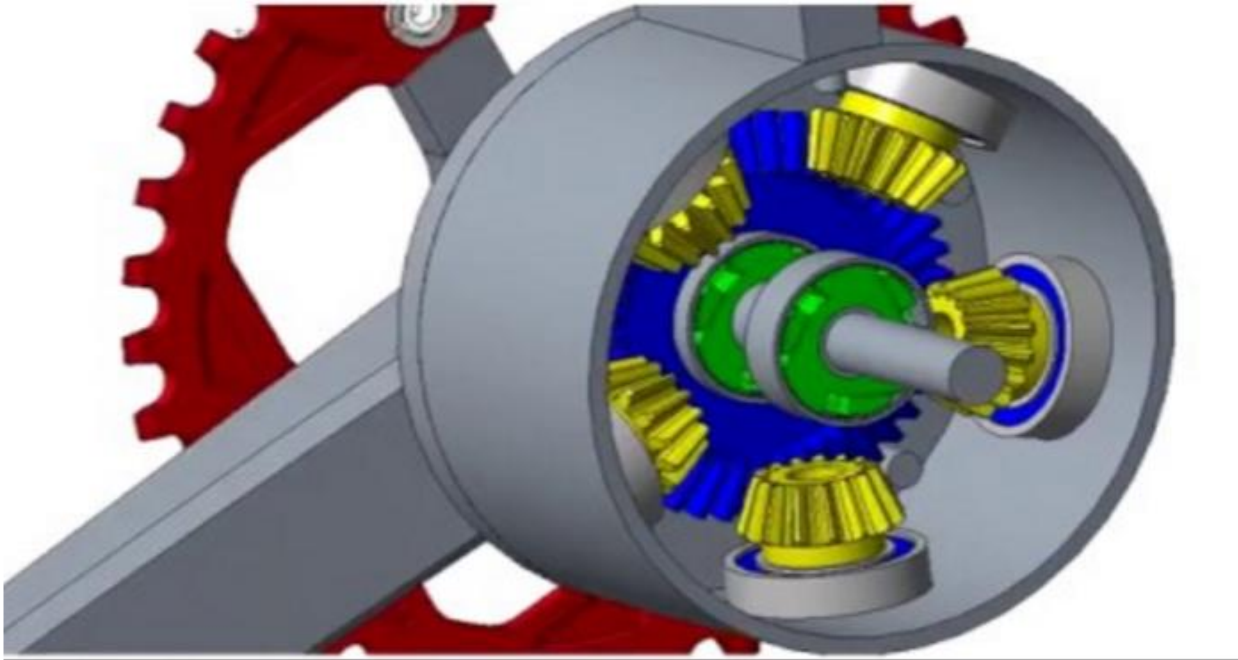

Figure 17: Internal view of RLT

The RLT consists of bevel gears, (in background of picture in blue), 2 ratchet and pawls (in green), an inner shaft, (middle grey cylinder), and pinions. Crank arms are attached at either end of the inner shaft. As the rider pushes a crank arm downward, the ratchet and pawl on the corresponding side engage and rotate the inner shaft, while the ratchet and pawl on the other side move freely. The bevel gear pinions (around inner diameter, in yellow), spin the opposite crank arm and bevel gear (not pictured) up, at the same rate that the other crank is being pushed down. The process is then repeated when the opposite crank arm is pushed downward, and continues throughout the bicycle's use.

The bevel gears used in the RLT are made of SUS303 stainless steel. There are also multiple bearings used in the mechanism. The five bevel gear pinions are held in place in the bevel housing using roller bearings. The two large bevel gears are held in the bevel gear seal plates by roller bearings as well there are bearings in each of the crank arms, where they attach to the large bevel gears. The bearings assist in reducing friction between the various moving parts, as well as preventing wear.

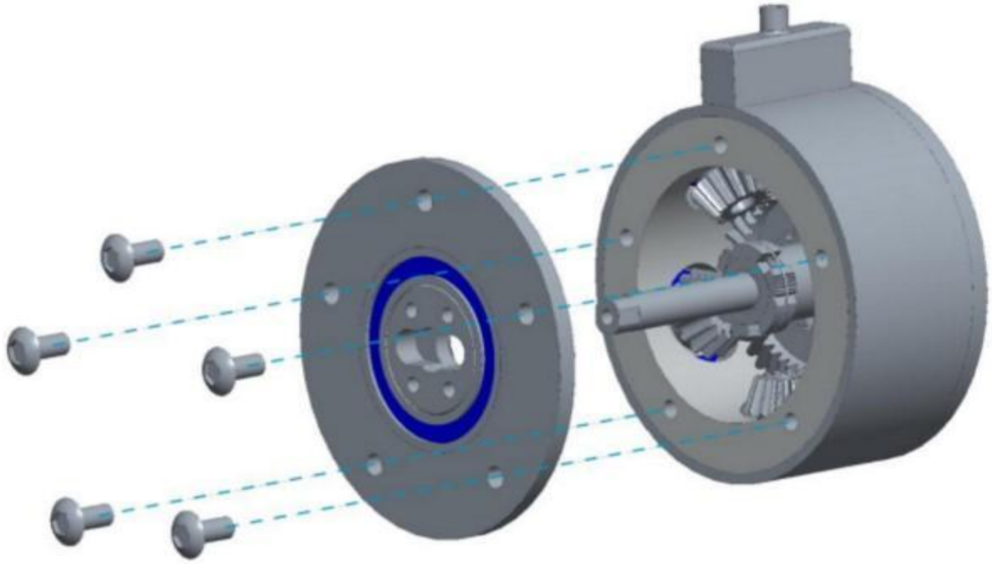

Figure 18: An exploded view of the RLT

Two ratchet and pawl systems are used in the bicycle prototype and are attached to the inner shaft. These were installed in opposite directions, to enforce the upwards/downwards motion of the crank arm. As one crank arm is pushed down, the corresponding ratchet and pawl engage, rotating the shaft and moving the bicycle forward. During this time, the opposite ratchet moves freely, allowing the bevel gear pinions to move in the corresponding direction as well. As the other crank arm is pushed, the process switches, and repeats as each crank arm is pedaled.

The chain ring is attached to the chain ring adapter, which is attached to the axle. The chain wraps around the chain ring, which is connected to the rear wheel of the bicycle, which is driven forward when the crank arms pedal and move the RLT mechanism.

The bicycle also consists of two crank arms, on either side, as pedals. These are attached to the two large bevel gears inside the RLT. These crank arms were manufactured using in the machine shop using the CNC as well as several other tools, and have a new shape to provide perfect alignment and strength. The pedals attach to the end of each crank arm.

9.2 Frame Components

The bicycle frame was manufactured out of chromoly tubing, due to its light weight, low cost, and high strength. The S&S couplings and bottom bracket are two main features of the frame. The entire frame weighs only six pounds.

The S&S couplings allow the rider to disassemble the frame for shipping purposes. As requested by the sponsor, the HANSCycle is to be able to be disassembled and shipped in a 26x26x10 inch shipping container. The couplings can be separated by hand. The bracket on the bottom of the frame is intended to accommodate a standard bicycle crank, if desired. This would require the rider to remove the RLT and connect the standard crank to the rear hub, which would change the function of the bicycle.

10. OEM Parts

There are three main OEM components used in the HANSCycle prototype. These include the disc brakes, the internally geared hub, and the clipped pedals. Below is a brief description of each:

1. The hydraulic disc brakes allow the ride to quickly stop the bicycle, even at high speeds. When the brake lever is squeezed, the piston inside the master cylinder is actuated, moving the fluid towards the brake caliper, causing pressure in the brake system. This pressure pushes the pistons towards the rotating wheel, slowing down the bicycle by use of friction.
2. The 11 speed Shimano hub allows the rider to use the gear shifter on the right handlebar to change speeds. This allows the rider to find a comfortable level of resistance, depending on the setting and conditions of the bicycle ride. The internally geared Shimano hub is attached to the rear wheel and chain, which allows the rider to switch gears for maximum performance.
3. Clipped pedals allow the rider to attach compatible footwear, in order to generate power on the upstroke as well as the down stroke. The pedals are attached to the crank arms, but compatible footwear must be purchased separately.

17. References

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4. Holland, Connor. *Needs Assessment: Team 20: HANS Cycles*. Rep. 2015. Print.

Appendix A

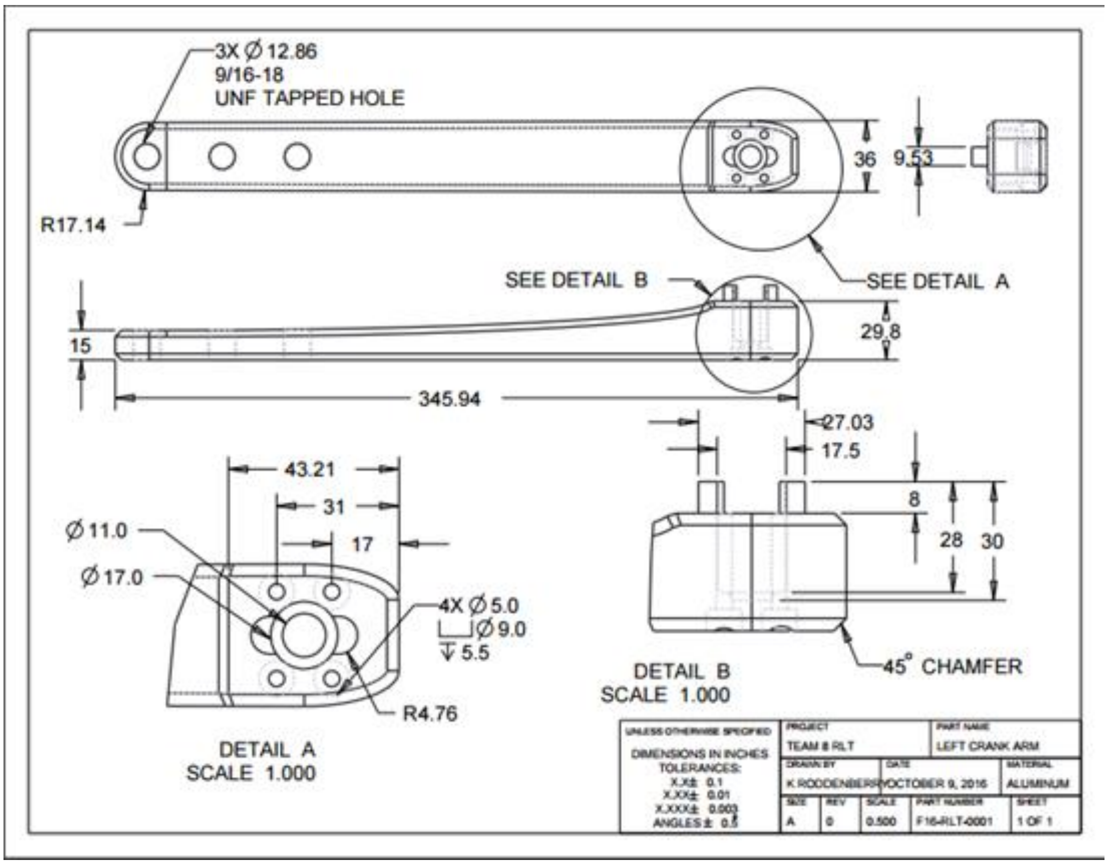

Figure 19. Detailed drawing of the revised crank arms.

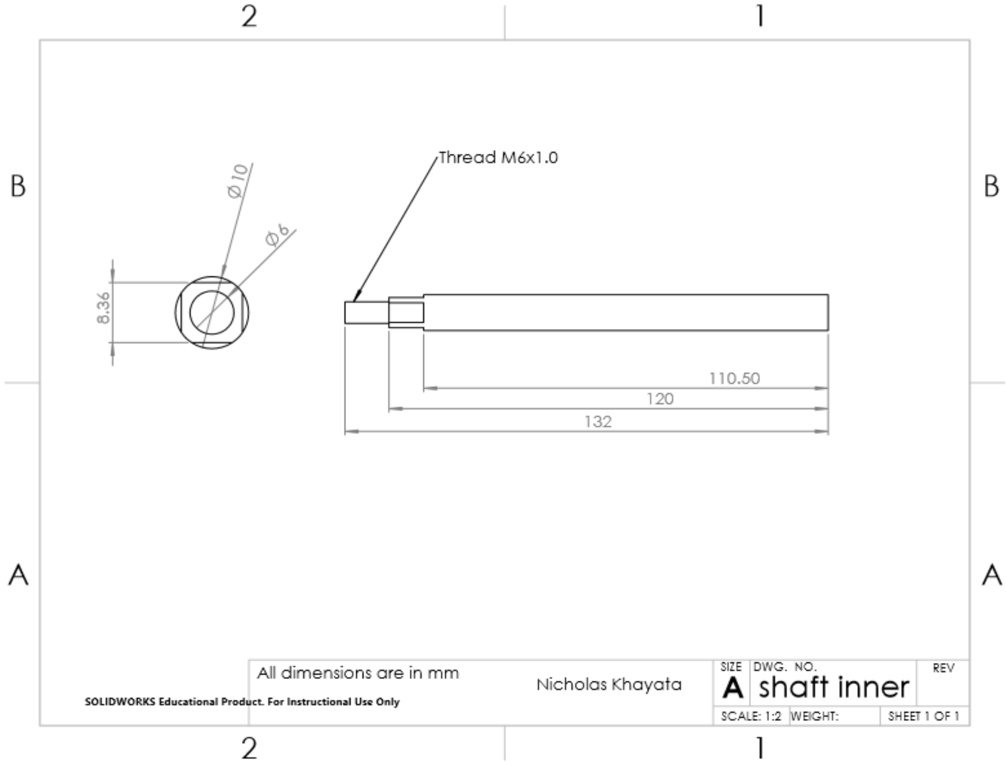

Figure 20: Drawing of inner shaft

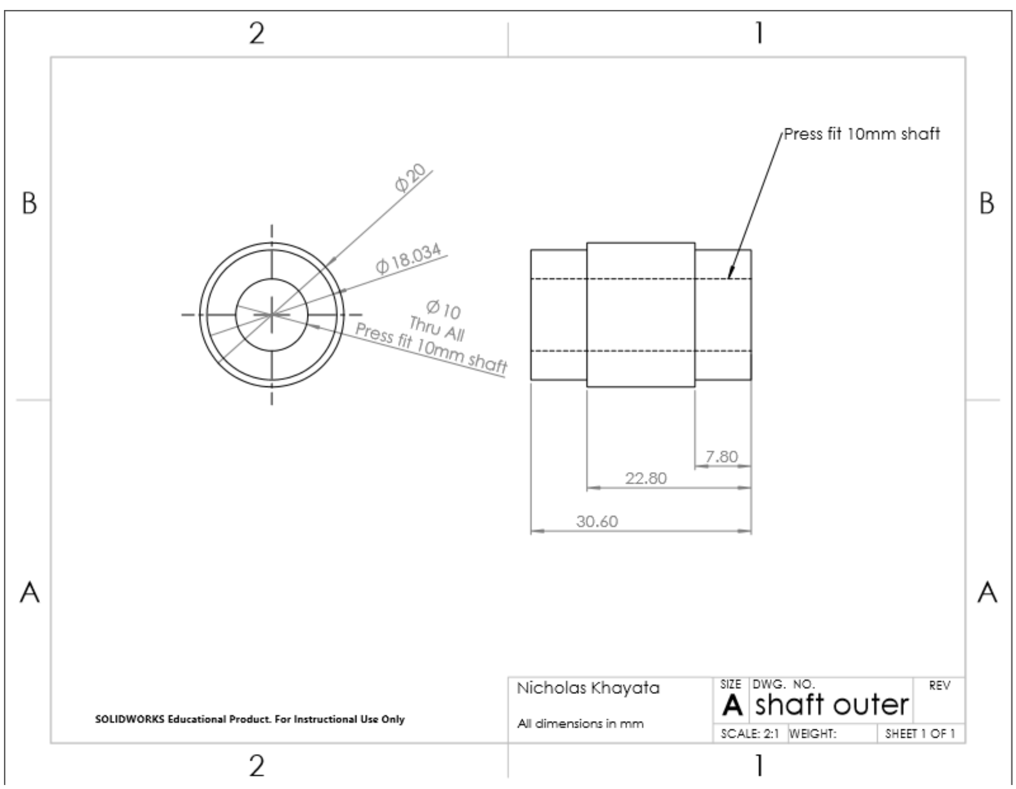

Figure 21: Drawing of outer shaft

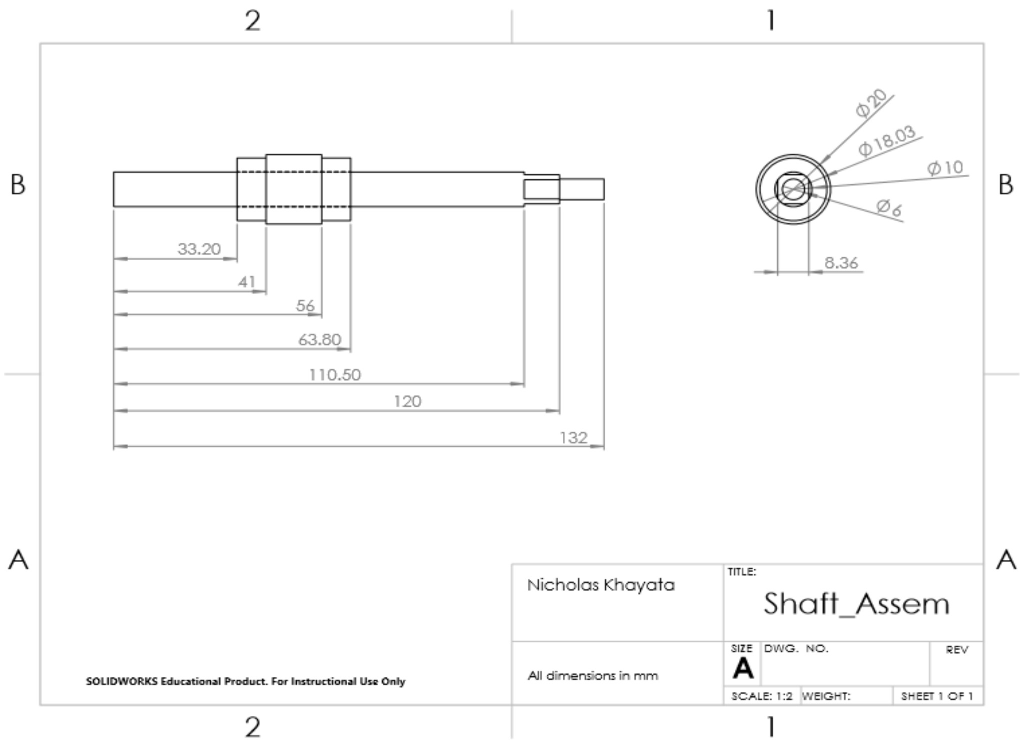

Figure 22: Drawing of shaft assembly

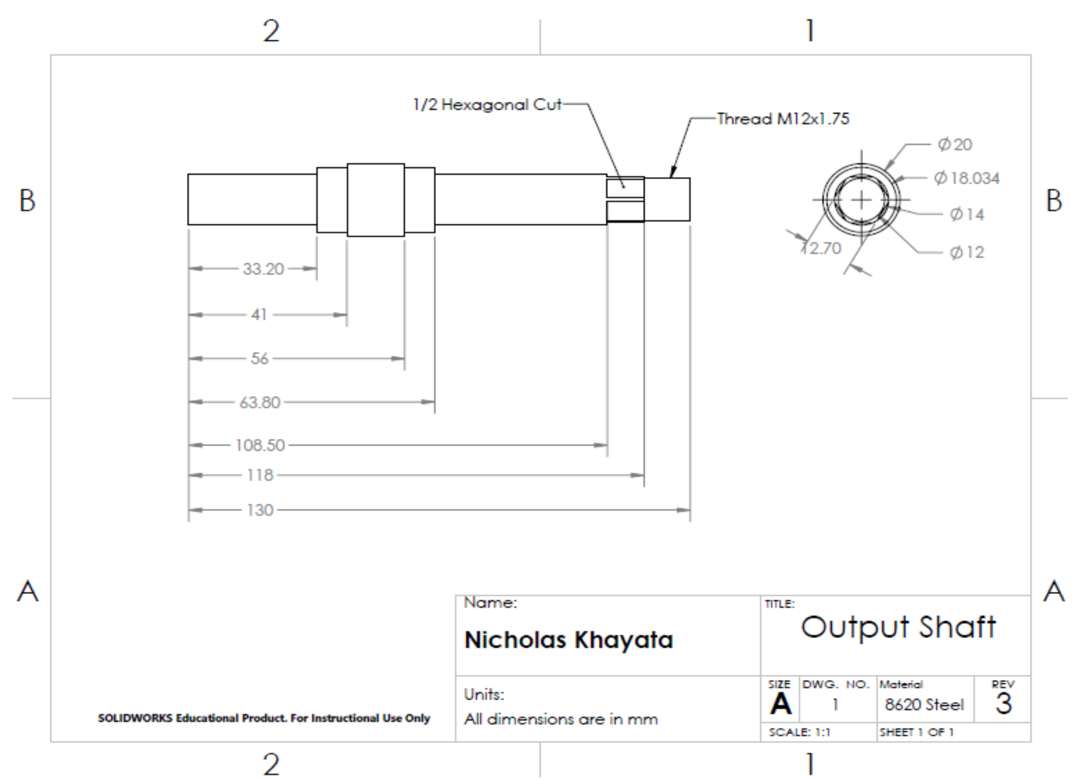

Figure 23: Drawing of Final Output Shaft

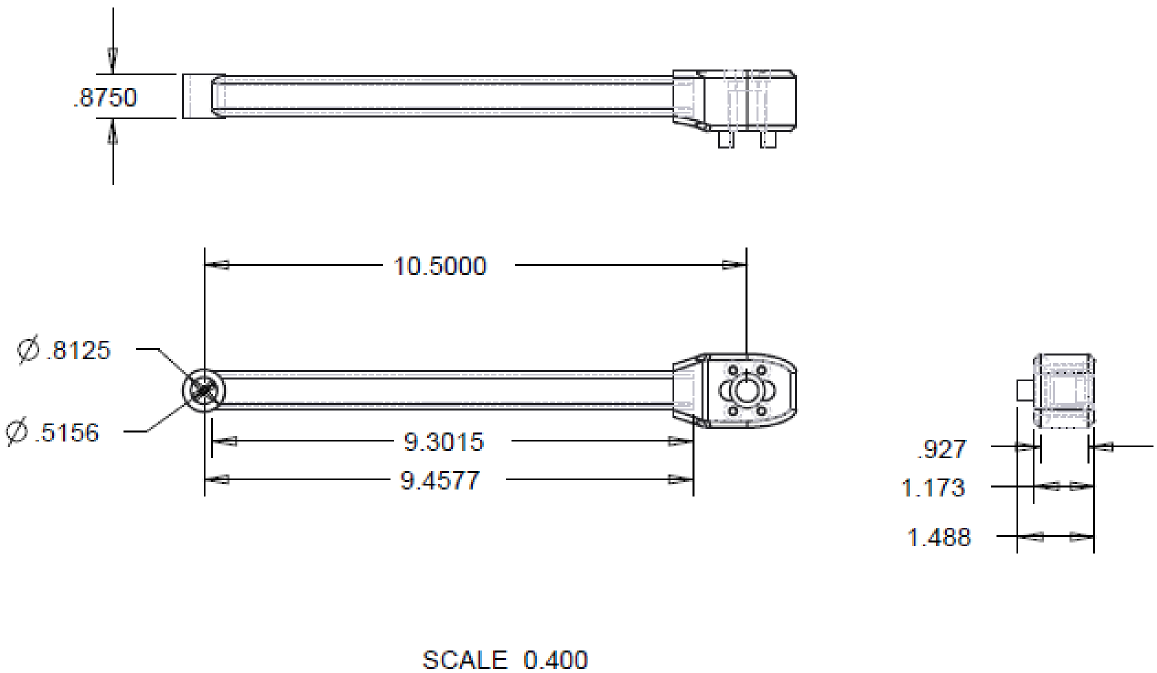

Figure 24: Drawing of Final Crank Arms

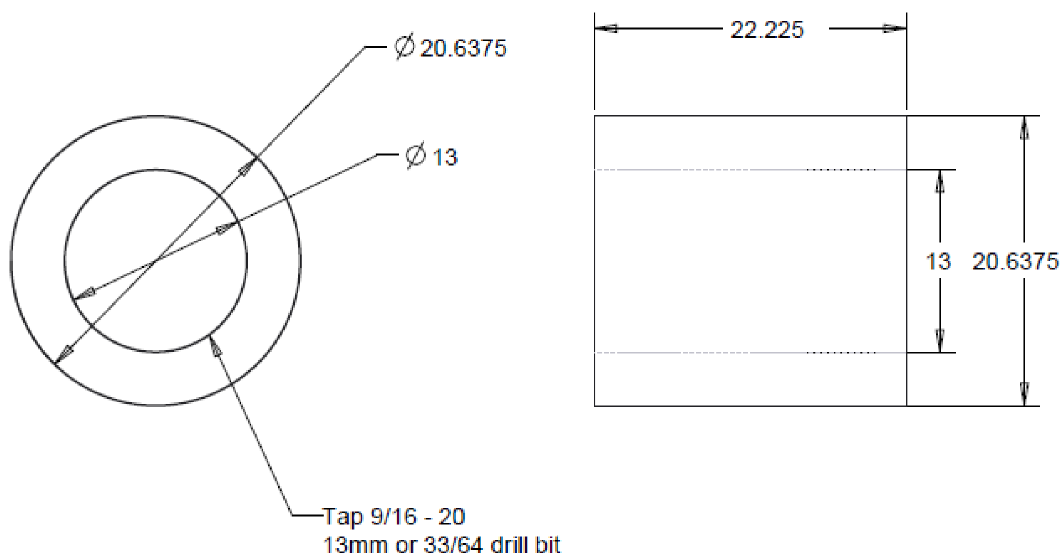

Figure 25: Drawing of Crank Arm Bung

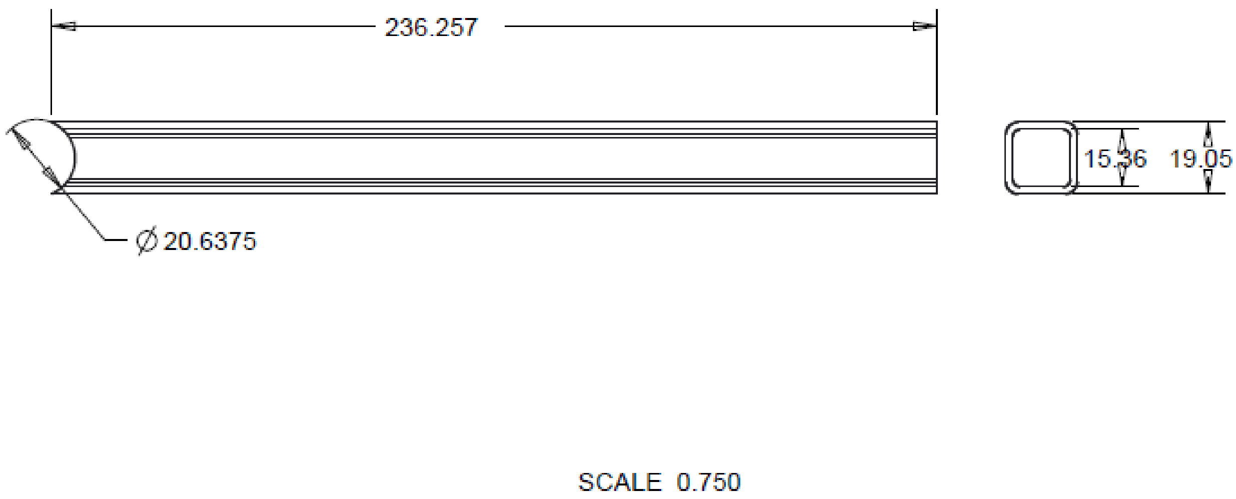

Figure 26: Drawing of Crank Arm Square Tubing