The Development of the HANSCycle RLT

Final Fall Report

Team 8 Members

Nicholas Khayata	nak12@my.fsu.edu
Darren Beckford	dbb11c@my.fsu.edu
Ali Pustelniac	agp12@my.fsu.edu
Michael Roddenberry	mkr14b@my.fsu.edu

Faculty Advisor

Keith Larson

Sponsor

Gordon Hansen

Instructors

Dr. Chiang Shih

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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 Tallahassee 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 of 2017 in their work to further improve upon the earlier RLT design work.

Abstract

Team 8 was given the task of continuing last year's senior design Team 20's work on the HANSCycle. The HANSCycle is a bicycle that utilizes a reciprocating lever transmission (RLT) that was invented and patented by our sponsor Gordon Hansen. Team 8's main goals for this project included making sure that the (RLT) was in complete working order, the bicycle is capable of rolling backwards freely (when pushed not pedaled) without locking up, and testing the RLT in various setups to compare it to the traditional bicycle as well as determine its capabilities. New crank arms that are made entirely of steel to make sure shearing doesn't occur have been designed and are going to be built and implemented at the beginning of next semester. A new shaft material has been sourced and will be machined as well as case hardened. Lastly new ratchet and pawls and continued research on possible alternatives are also being looked. When all the failed components have been fixed Team 8 will be able to test the RLT at full capacity and receive the data that Gordon Hansen requires.

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 ratios. 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 places for 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 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. So 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. Project Statement

Team 8 has been tasked with developing a working Reciprocating Lever Transmission bicycle. Then the team must test the prototype and compare values such as torque, cadence rate, work, and speed, with values of a Traditional Bicycle. This project hopes to prove that a reciprocating lever bicycle can obtain similar results in performance compared to a traditional bicycle but also cause less stress and damage to the riders joints.

"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."

3. Project Scope

Gordon Hansen, the HANSCycle sponsor, believes his redesign of the traditional bicycle will lead to a new age of bicycling. He has redesigned the traditional bicycle in an effort to maximize efficiency and ease stress on the user's joints. He believes that the two "dead spots" on a traditional bicycle mechanism 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 redesign. The new design consists of an RLT mechanism that makes bicycling more efficient and less stress-inducing to the rider.

Below, Figure 1 displays the disassembled bicycle components that were used to construct the bicycle last year.

Figure 1: Disassembled bicycle components

The bicycle is still intact with the above parts, but certain aspects require improvement. Specifically, the driveshaft and clutches must be made stronger, in order to be able to support the increased torque from the longer cranks and Reciprocating Lever Transmission, seen below in Figure 2.

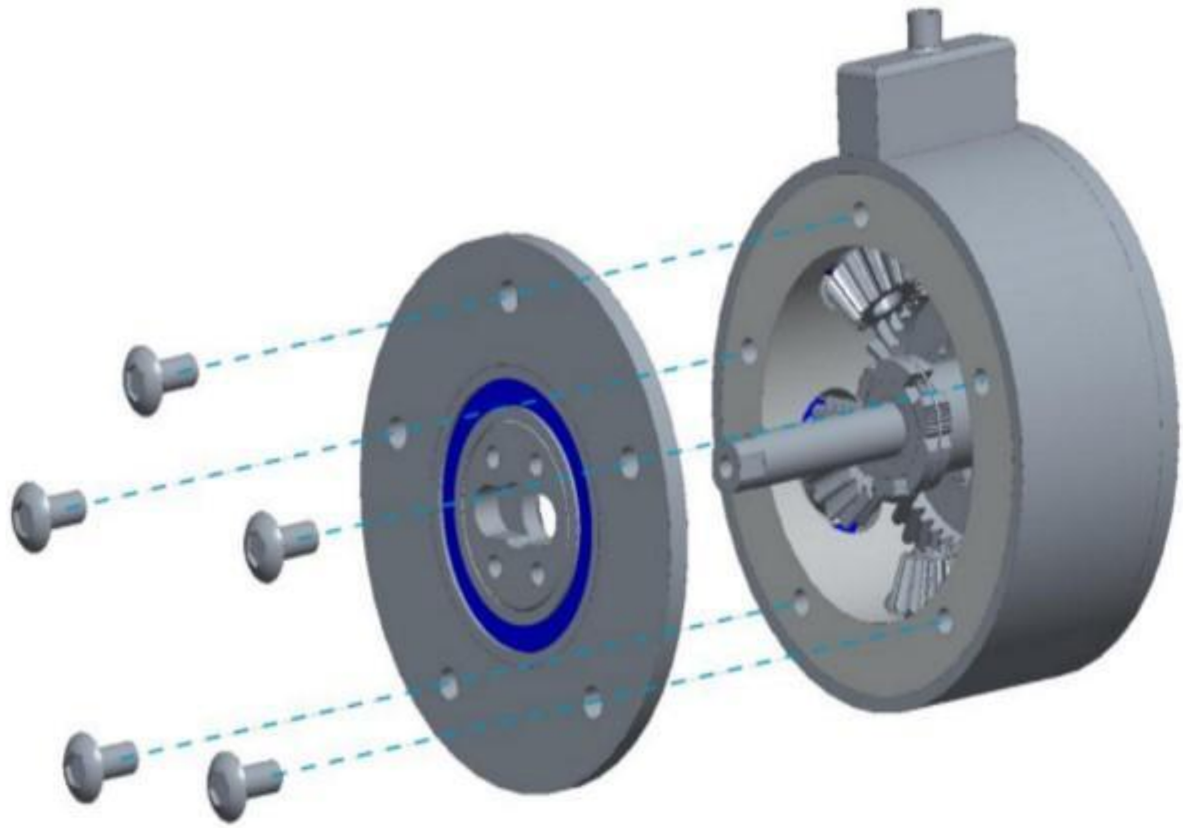


Figure 2: Reciprocating Lever Transmission CAD exploded view

Gordon Hansen has also requested, if possible, that the team try to find a way to alter the position of the bike rider. Currently, the seat and handlebars are at a position that causes the rider to lean forward. For optimum comfort and use, an upright position is favored. While this is a request from the sponsor, it was not one of his priorities, so the team will focus on the actual function of the mechanism before adjusting the design for rider comfort.

4. Project Objective

One primary objective is to design and test a new bicycle design using up to 12” crank arms that reciprocate in arcs no greater than 100 degrees. The new design should improve the comfortability of uphill riding. Building on the work of last year’s team, team 8 will redesign the reciprocating lever transmission (RLT). The new reciprocating lever transmission should be designed so the clutch will be able to drive the bicycle forward and backwards. Using the test rig to provide performance data of the bicycle is another important objective. The 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.

4.1 Constraints

- The bicycle must be designed for use with 26” wheels

- Bicycle must disassemble into a 26”x26”x10” packaging box

- Utilize crank arms up to 12”, with an arc of no more than 100 degrees

- Last year’s prototype must be used

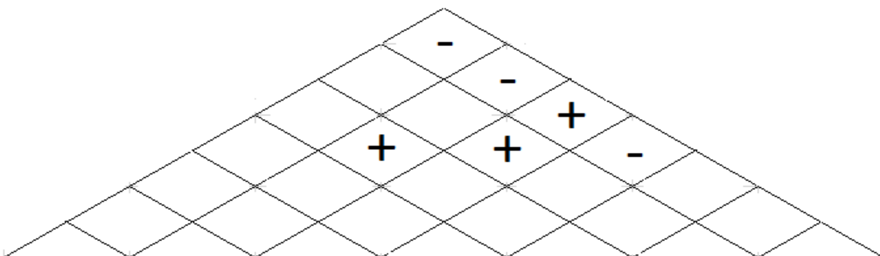
4.2 Methodology

In order to successfully complete this project, Team 8 has agreed upon various methods of organization, planning, and communication. Nicholas Khayata has been designated as the Team

Leader. As Team Leader, he is in charge of delegating tasks to fellow group members, along with keeping in close contact with the sponsor, finalizing purchase orders, and ensuring an overall productive work environment. Darren Beckford, the Financial Advisor, is responsible for creating purchase orders, managing the budget, and keeping a record of all costs throughout the project. Michael Roddenberry, the Lead Mechanical Engineer, is responsible for knowing and justifying all mechanical design decisions, and relaying the information to fellow team members, advisor, and sponsor. As the Organizational Lead and Webmaster, Alison Pustelniac is in charge of recording minutes and details of all group, advisor, and sponsor meetings, along with keeping the Google Drive and website up to date, where all project documents will be kept in an orderly fashion.

All team members are responsible for working in a cooperative and professional manner, as well as fulfilling all designated duties. This includes good communication between the group, advisor, and sponsor throughout the project span. Communication between group members will primarily be through a group text message, along with weekly meetings. Group meetings will consist of finalizing any deliverables or necessary assignments, discussing upcoming tasks, and voicing questions or concerns. Bi-weekly meetings will occur with Dr. Gupta and Dr. Shih on Tuesdays at 4:15pm, where project status will be discussed and input and advice will be given. Bi-weekly meetings will also be held on Thursdays with the sponsor, Gordon Hansen, to discuss progress, receive input, and ask any questions. Any additional meetings or discussions will be arranged on a necessary-need-basis.

In addition to communication, the methodology and planning of this project is very important in order to have a successful project. A House of Quality (HOQ), a type of priority matrix which relates various customer requirements and prioritizes all elements, can be seen below in Figure 1. Important aspects have been listed, rated, and related to one another, in an effort to determine importance. The HOQ will assist the team in prioritizing various aspects of the project, thus maximizing productivity.



	Wheel Size	Weight	RLT	Component Choice	Material Choice	Torque Output	Frame Design	Total	Rank
Ergonomics	4	6	9	10	2		10	41	2
Cost	1	1	8	8	9		2	29	4
Performance	6	7	8	6	7	10	4	48	1
Size	9	8	2	1	1	5	8	34	3
Wheel Size	10	2				4	5	21	5
Reliability			6	3	9			18	6
Total	30	24	33	28	28	19	29		
Rank	2	6	1	4	5	7	3		

Figure 3: House of Quality (HOQ)

The House of Quality was created to properly prioritize various aspects of the project. The left column lists customer/sponsor desires and requirements. The top row lists engineering design attributes. The triangle shaped section on top shows relationships between the engineering design points. A plus sign represents a strong correlation between the two connecting design aspects, while a minus sign represents a weaker relation between the two aspects. In the middle section, the numbers represent importance of each aspect, relating the sponsor requirements and engineering aspects. The ratings from one through ten represent the scale of importance, 1 being weak, and 10 being strong. The totals and rankings are the final addition of the ratings, and have been used to determine where to place priority for this project. As the ratings show, the RLT, Wheel Size, and Frame Design were found to be the most important engineering characteristics, while Performance and Ergonomics were found to be the most important customer requirements. Moving forward, the team will focus on successfully completing these characteristics, while also incorporating the other aspects listed in the HOQ. Additionally, a Gantt Chart, (seen below in Figure 4), has been created, to show a timeline of the various steps throughout this project, and when they are expected to be completed.

5. Deliverables & Assigned Resources

As discussed in the Methodology section of this report, the HANSCycle team has designated certain responsibilities to certain team members, to be followed throughout the course of this project. To ensure that the project stays on track, the team has created a Gantt chart to track required class deliverables. Additionally, the team has made a tentative schedule for progress, which will be followed as best as possible and adjusted when needed.

The team has been meeting one to two times each week to discuss upcoming class deliverables, as well as work on design concepts and various approaches for the project. The team is also meeting with the sponsor, Gordon Hansen, biweekly in order to keep him up to date, as well as get his input on various project plans. Biweekly meetings are also held with class instructor Dr. Shih to present the latest design progress and ensure the project is on track. The team has met with Keith Larson, the project advisor, as needed, and will continue to do so. His input is very helpful in the design and manufacturing of any parts that must be made or modified.

Initially, Team 8 met, discussed main goals and objectives, and created a Code of Conduct as well as a Needs Assessment, after meeting with all advisors and the sponsor. Then the team began reverse engineering, in order to find what needed to be done. Though last year's Senior Design team made good progress with developing the HANSCycle, there were many issues that arose and needed to be taken care of. For example, the output shaft was not installed correctly, which caused uneven torque forces during operation. The crank arms were also faulty, because of a misalignment of the bolt holes, causing the keys on the crank arms to take on more torque than was intended, causing them to shear and break. The bolts that were used throughout the prototype were also a lower grade, or weaker, than is necessary, so those had to be upgraded as well.

As these issues were being addressed, the team was also working on the webpage and various project reports and presentations throughout the semester. The reports and presentations were used to update the instructor, sponsor, and peers on the status of the project, as well as to discuss issues and upcoming actions and goals.

The Gantt chart below in Figure 4 displays the team's desired progress and work timeline, which is more flexible than the schedule of required deliverables.

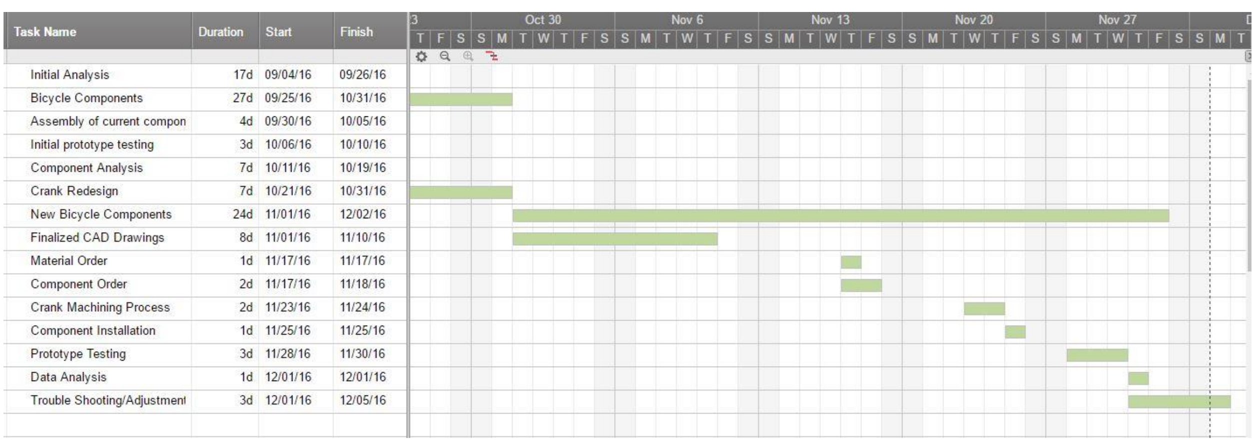


Figure 4: Project Progress Gantt Chart

The above Gantt chart will assist the team in ensuring that the project stays on track, while also being flexible enough to be adjusted as needed. The purpose of a Gantt chart is to set out a desired goal or track for the project. There are various stages of the project that must be completed prior to beginning the next steps, as well as set dates that must be followed, and the Gantt chart is a visual representation of these dates and timelines. The team hopes that the listed strategies and schedules will assist in making this a successful project, as well as guiding the schedule. It should be noted that if any problems arise, the Gantt chart may require rescheduling, in order to reassess and continue project progress.

6. Product Specifications

The long lever bicycle as a whole must be able to perform as well as or better than a traditional bicycle, while causing less taxing pressure on the user's joints. It must also implement the RLT which allows for reciprocating motion; meaning it can produce power in both the upward and downward stroke. Overall it must be an everyday means of transportation while being both user friendly and high performing.

6.1 Design Specifications

The long lever bicycle must be designed for everyday use such as commuting to work, but also must be able to generate enough power to climb hills. The bicycle frame on the current long lever bicycle is very similar to that of a mountain bike. Pending the results of the testing data, Team 8 may redesign the frame to be more like a recumbent frame. The hope is that a recumbent style frame may give the user a more comfortable seated position while also being able to generate more power and torque than the mountain bike frame.

The crank arms must be redesigned in order to fit the current prototype. The current crank arms have shearing components that must be fixed. On top of the shearing the holes drilled into the crank arms do not line up. With the new design of the crank arms, the drawing will be fixed so that the holes will be lined up. Due to the shearing pieces on the current crank arms, Team 8 will properly re-machine the crank arms to improve the shearing pieces. After redesigning and properly re-machining the holes in the crank arms, Team 8 negotiated with our sponsor and advisor to further develop better crank arms. It was decided that the team will also use a stronger material for the crank arms to replace the current aluminum crank arms. The Aluminum crank arms are not strong enough to handle the required torque. They also has a negative effect on the bolts used to hold the crank arms in place. The material that was selected for the new designed crank arms was steel. The steel will come from an online vendor named speedy metals. With the new steel crank arms, testing will be much more efficient and team 8 will be able to get accurate data to help reach the goal of optimizing the performance of the RLT.

Another design change includes implementing a one way keyed bearing into the RLT. Currently the HANSCycle only can move forward which hinders its maneuverability and practicality. This one way keyed bearing will be added into the center of the sprocket. This will serve to connect the sprocket and shaft in a manner that only allows for forward motion. When engaged in a forward motion it will serve as part of the shaft. However, if the bike were to roll backwards the bearing would free spin. This free spin will allow the bike to roll backwards without applying torque to the center axle. Our first design iteration will implement a CSK10PP one way bearing with keyway sprag freewheel backstop clutch. The selection of this design was largely due to the size requirements of the RLT. It has very limited space and but be able to fit on to the axle which has a diameter of only 10mm. This bearing will be easily fitted to the current parts with some minor machining and design, however there is some doubt that this particular bearing will be strong enough to handle the increase of torque that a long lever bicycle will produce. If proven, this part could be improved upon to withstand greater forces to handle the daily torque applied to a commuter style bicycle.

6.2 Performance Specifications

The main performance specification is to get the long lever bicycle to produce enough torque and power to have the ability to climb a hill. By using the newly designed adjustable crank arms, Team 8 will be able to test the long lever bicycle to see which length will produce the best results.

As previously described, another important design specification is to get the long lever bicycle to move backward. This is a vital aspect in making the long lever bicycle more consumer friendly. As of now, there is a ratchet and pawl design in the RLT transmission that is prohibiting the long lever bicycle from being able to move backward. Team 8 is in the process of finding a way to utilize one-way bearings to replace the ratchet and pawl. The one-way bearing may allow the bicycle to move backwards.

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 bearing, and locknuts were the parts that began to break. Almost every crucial component of the RLT has broken 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. It caused a setback, testing could not take place because of the broken pieces. Team 8 had to purchase even more new parts to replace the broken ones. Attending to the broken parts, pushed back the scheduling and in consequence we were not able to test the HANSCycle at its highest efficiency. 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 our materials. After ordering the metal for the new crank arms, Team 8 was waiting on the metal come in. Unfortunately, The metal was delivered to the school but Team 8 was never notified. It was not until 3 weeks later that one of the team members stumbled upon the metal that was ordered. Prior to this mishap team 8 was on schedule to get the new designed crank arms machined. Due to this 3 week mishap it was not possible to machine and build the new crank arms at the end of the fall semester as planned.

In addition to the metal being lost, one of the vendors carrying a very important part, the replacement ratchet and pawl, was not accepting the payments from the school. The P-card that was used for last years and this year's team was rejected this time. Different types of purchases was attempted but none went through. As a consequence the ratchet and pawl has not been ordered although it is still needed. This is yet another issue to cause a big setback on the building of the working HANSCycle prototype. Possible solutions include finding an alternative, to the ratchet and pawl system or asking the sponsor to purchase the ratchet and pawl then reimburse him. All in all this is another setback for team 8.

In conclusion Team 8 has experienced some unusual setbacks dealing with the broken parts as well as procurement issues. Therefore Team 8 was unable to fulfill fall semesters goals of building new cranks arms as well as building and testing the new prototype. However, in the spring semester Team 8 does not expect any delays or procurement issues to cause a setback in scheduling or reaching the goals. If no other parts break and procurement runs smoothly, team 8 will undoubtedly reach all of its semester goals.

7. Conceptual Design

The first aspect of the HANSCycle that Team 8 has chosen to focus on are the crank arms that failed due to improper construction. The new crank arms implement a very similar design but fix the underlying issues that plagued the previous rendition. The most important aspect that has been fixed are the mounting components. The new design has properly dimensioned holes and is toleranced better for this application. The new crank arms also implement multiple holes at 9, 10.5, and 12 inches to allow for varying pedal location. The cad model of the crank arm as well as the drawing can be seen in figure 5 below. A larger version of the drawing is available in Appendix A.

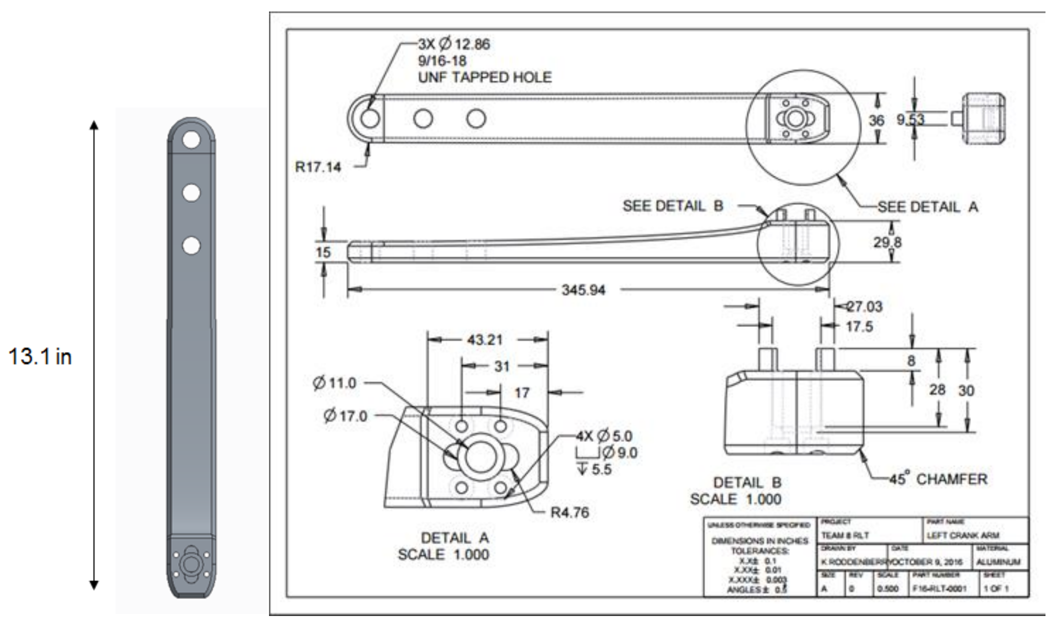


Figure 5: Revised crank arms with multiple pedal locations. (More detailed in Appendix A).

Another design considered by Team 8 was a two piece design composed of both steel and aluminum. In addition to the misalignment of the holes, the previous keys in the crank arms were made from aluminum. These narrow pieces of aluminum sheared when put under large amounts of torque typical of pedaling a bicycle or in this case, a high torque long lever bicycle. This two piece design avoided this by implementing a steel base to maximize strength where needed, and still allows the usage of the previous crank arms. This design would include a steel base with properly aligned holes and keys for installation in addition to a locking system to join the two materials together in a rigid manner. This design can be seen below in Figure 6.

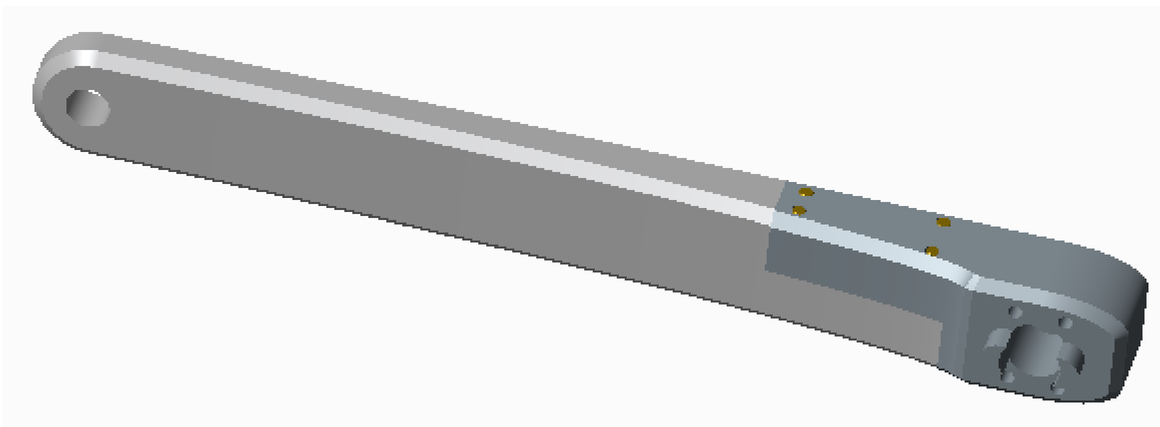


Figure 6: Two piece design with steel and aluminum components

The third rendition is an all steel design. This design will have a locking base with the same hole pattern and keys as the previous designs so that it will hold firmly to the RLT. The crank arm portion will be constructed from a steel tubing. There will also be three welded tubes that will be tapped for the pedal bolt to allow for adjustability when testing. Once an optimum crank length is determined, a design much like the one shown below in Figure 7 will be designed for further testing. Afterwards a more presentable design may be made to have a good visual appeal.

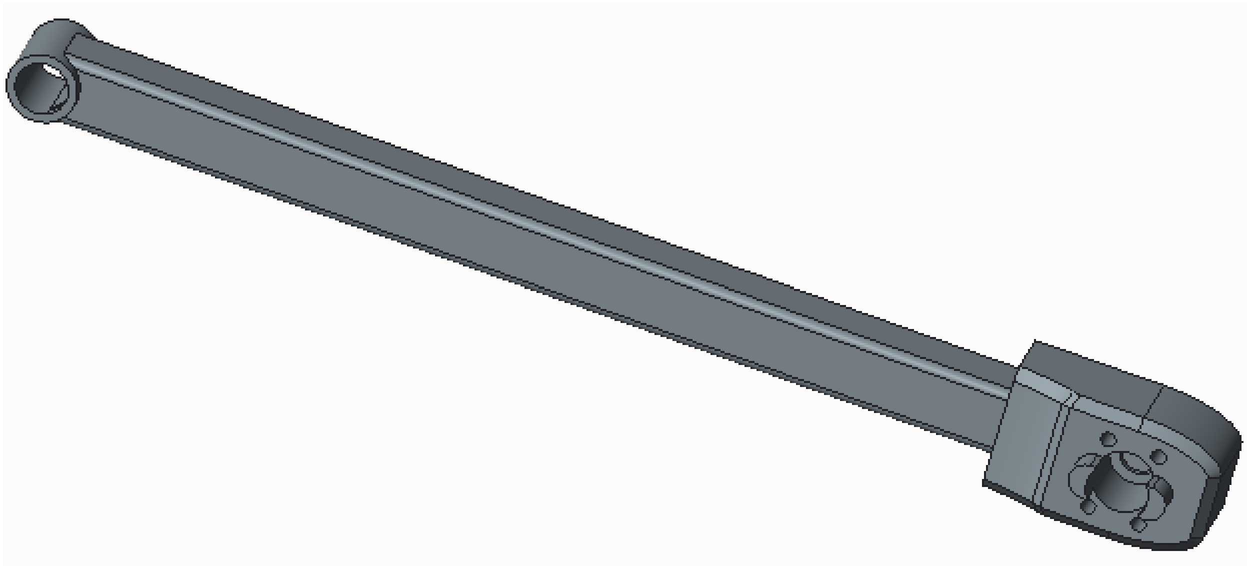


Figure 7: One piece design constructed from all steel

The next area that Team 8 has decided to focus on is the output shaft. The current output shaft is made of multiple materials because it failed last year during testing. It also has a lot of play in all directions because it is not properly sized and toleranced. In order to fix this problem, the proper material needs to be applied. After some research and looking at similar applications, two main materials have been chosen. The first is titanium, which has one the greatest strength to weight ratios and would work well because of the small size of the output shaft. However, titanium can be very expensive and difficult to machine properly. The other material choice is 8620 case hardened steel. The 8620 steel was chosen over the 4130 steel. They both are very similar in properties. 4130 steel is known for through hardening which means it is hardened all the way through the material. It is easily heat treated and slightly stronger than most steels. The benefits of 8620 is that it has great torsional strength but can be case hardened. In addition to being strong, this material is much easier to machine than titanium and 4130 steel and due to the small size, an additional weight will not be an issue. Therefore we went with the material that is easier to machine while also being used for similar applications that we will be using it for.

8. Finite Element Analysis (FEA)

Prior to having our 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.

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 load 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.

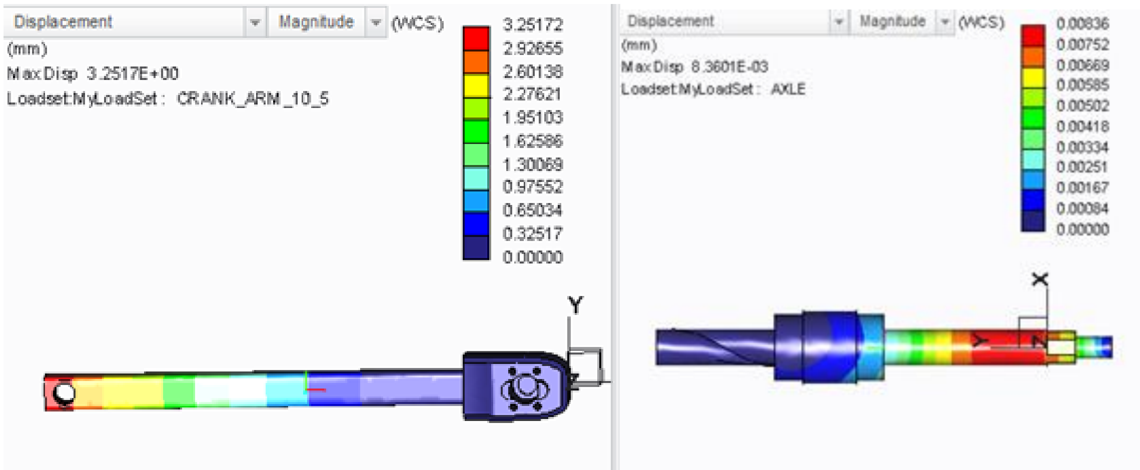


Figure 8. FEA of Crank Arms (left) and Output Shaft (right)

9. Budget Update

Team 8 has been allotted a $2000 budget. Our updated budget amount is $1,721.7. All of our purchases came from four vendors. VXB bearing is where we purchased the one way bearing for our HANSCycle. The newly purchased one-way bearing will have a keyway to help provide backward motion of the HANSCycle. Due to the wear on the current ratchet and pawl design, team 8 decided to replace the ratchet and pawl mechanism with a new one. This product was purchased from the international vendor Trilton cycles which is located in the UK. We decided to use a new steel tube and steel bar material to use for the crank arms for better strength, we decided to also purchase a solid round steel bar to replace the current multi-material shaft, and we also decided to purchase a steel plate to help incorporate the keyway to fit the new one way bearing. All of these purchases were made from the same vendor, speedy metals. Lastly, Team 8 needed to purchase the correct bolts due to the sheared bolts holding the cranks arms in place. The new bolts will be strong enough to handle the torque and power needed to get the maximum performance of the HANSCycle. Below is the chart breakdown of the vendors and products purchased and it also shows the remaining budget at the bottom of the chart. Team 8 has a good amount of budget left over to help in case of any mishaps in the near future.

Table 1. Fall Semester Budget

#	Part	Material	Vendor	Cost	Qty.	Subtotal
1	One-way Bearing	steel	VXB bearings.com	$24.95	1	$24.95
2	rachet and pawl	plastic/steel	Triton cycles (UK)	$90.00	2	$180.00
3	square tube (5ft)	1018 steel	speedy metals	$5.95	1	$5.95
4	round bar (shaft)	8620 steel	speedy metals	$6.89	1	$6.89
5	steel plate	A-36 steel	speedy metals	$29.53	1	$29.53
6	square bar	A-36 steel	speedy metals	$21.16	1	$21.16
7	socket screws	steel	Mcmaster	$9.82	1	$9.82
					Total	$278.30
					Remaining Budget	**$1,721.70**

10. Conclusion

The RLT transmission is a redesign of the generic bicycle transmission with the intent of eliminating the “dead’ spots on the top and bottom of each stroke in a traditional crank mechanism. At these dead spots no work is done and joint injury is possible for individuals with bad knees or other previous ailments. The RLT eliminates these “dead” spots with the use of a stepping motion which also allows for a greater amount of torque to be produced because longer lever arms can be utilized. With some changes and more research Team 8 will take the progress that was made last year and create a working model and a testing setup to gather the information required by Gordon Hansen.

Team 8 will work closely with both Gordon Hansen and Mr. Larson to properly continue moving forward in the research and development of the HANSCycle. Using a designated work schedule, good communication and set expectations Team 8 plans to take the previous prototype and move towards a more practical model that is capable of meeting all of Gordon Hansen’s expectations. These include but are not limited to: packaging within a 26”x26”x10” box, allowing for the transmission to be back driven allowing for reverse motion, a higher torque output for easier hill climbs, an ergonomic, easy to ride design, and integrated storage.

Currently Team 8 has a primary goal of getting the RLT to work correctly. One improvement that has been made in order to stabilize the RLT, was to create an additional mounting tab to reduce torque and play within the system. The original design was just one steel tab welded to the frame, and one steel tab welded to the RLT. These two tabs were bolted together,but the torque from the crank arms distorted the orientation of the system. To eliminate this play, another steel tab was cut by water jet, then welded to the RLT casing beside the other tab. This allowed the single tab welded to the frame to fit snuggly between the two when bolted together.

Moving forward, the RLT must be fitted with new crank arms. The current crank arms experience shearing within the keys, and the crank bolt holes do not line up with the holes drilled into the RLT. Another issue the team will have to face is internal slippage. While pedaling the HANSCycle, the rack and pinion system slips, which causes a grinding-like sound, because it skips many teeth before it catches. In addition to the increase in robustness, Team 8 would like to design it in a manner that allows for backwards motion.

11. References

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Appendix A

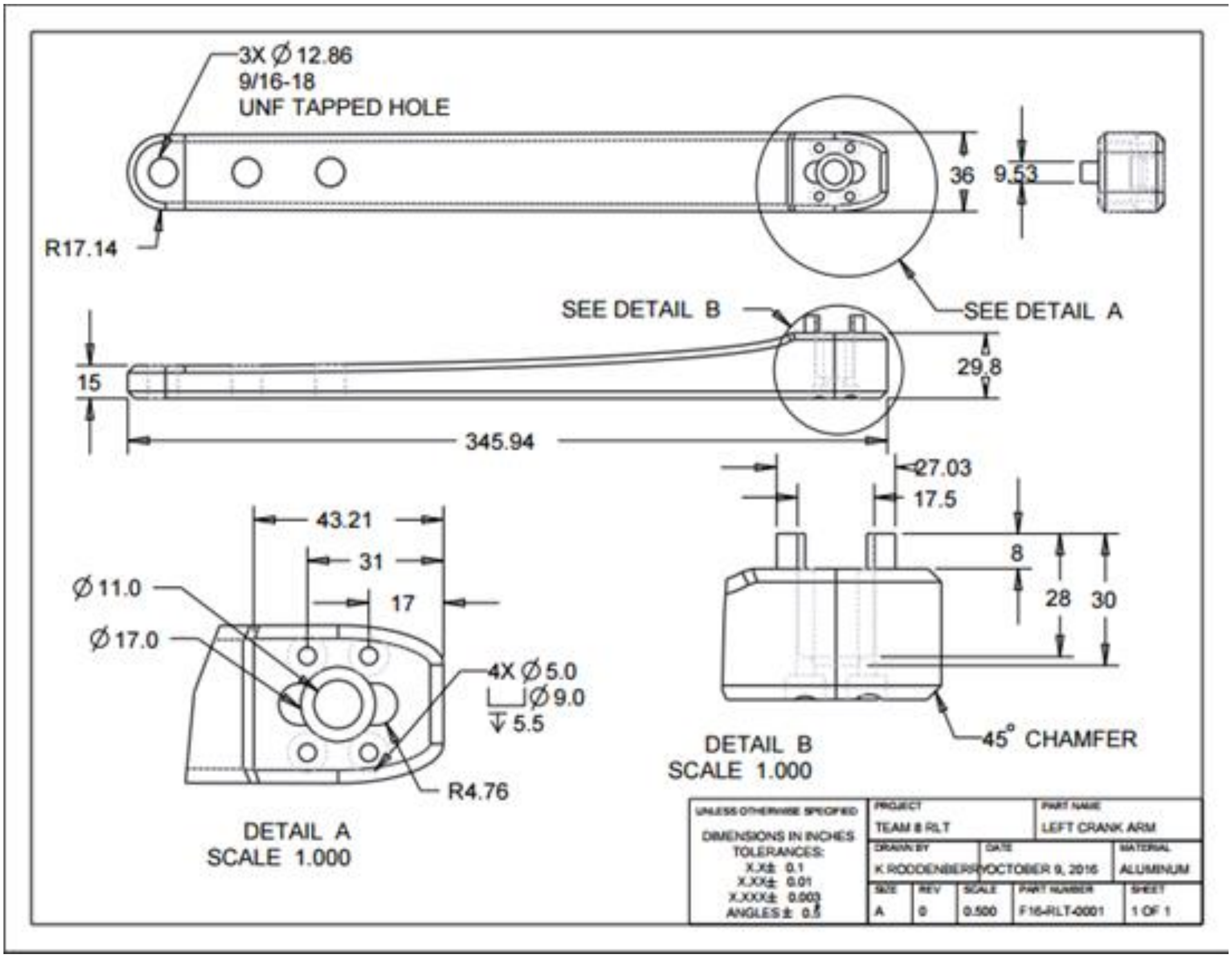

Figure 9. Detailed drawing of the revised crank arms.