ME Team 09: Sprag Clutch Addition to Reciprocating Lever Transmission

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Team 09 Members

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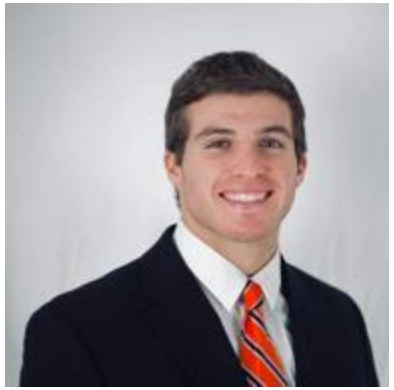

Samuel Evan Grambling
Quality Engineer
Senior, Mechanical Engineering

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Project Introduction

Angela Trent

Funding

We are thankfully sponsored by Gordon Hansen, AICP, holder of the patent for the Reciprocating Lever Transmission (RLT).

Gordon Hansen, AICP.

Project Objectives

- To make the addition of sprag clutches to the reciprocating lever transmission (RLT).
- Increase length of crank arms to 14 inches.
- Increase power generation by a minimum of 10% when compared to traditional bicycles.

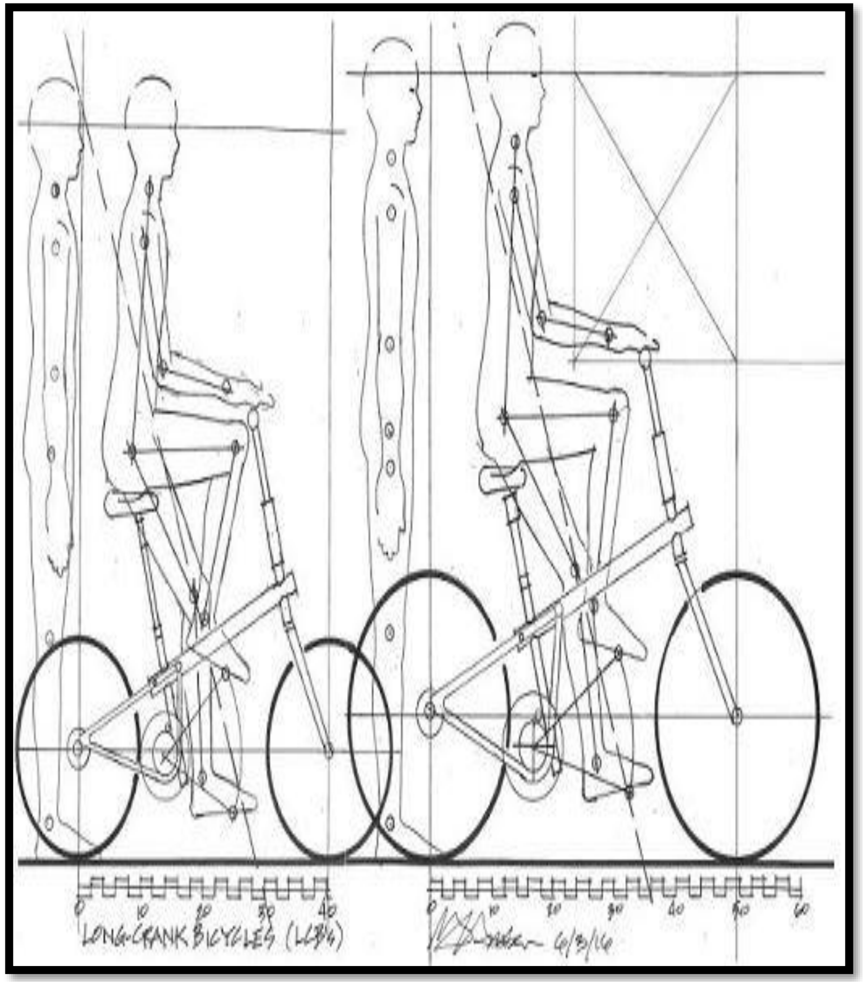

Figure 1. Bicycle utilizing RLT drawn by Gordon Hansen, AICP.

Project Description

- Improving the RLT design
  - Addition of sprag clutches
  - Longer crank arms: 14 inches
  - Improve gear meshing

- Budget: $2000

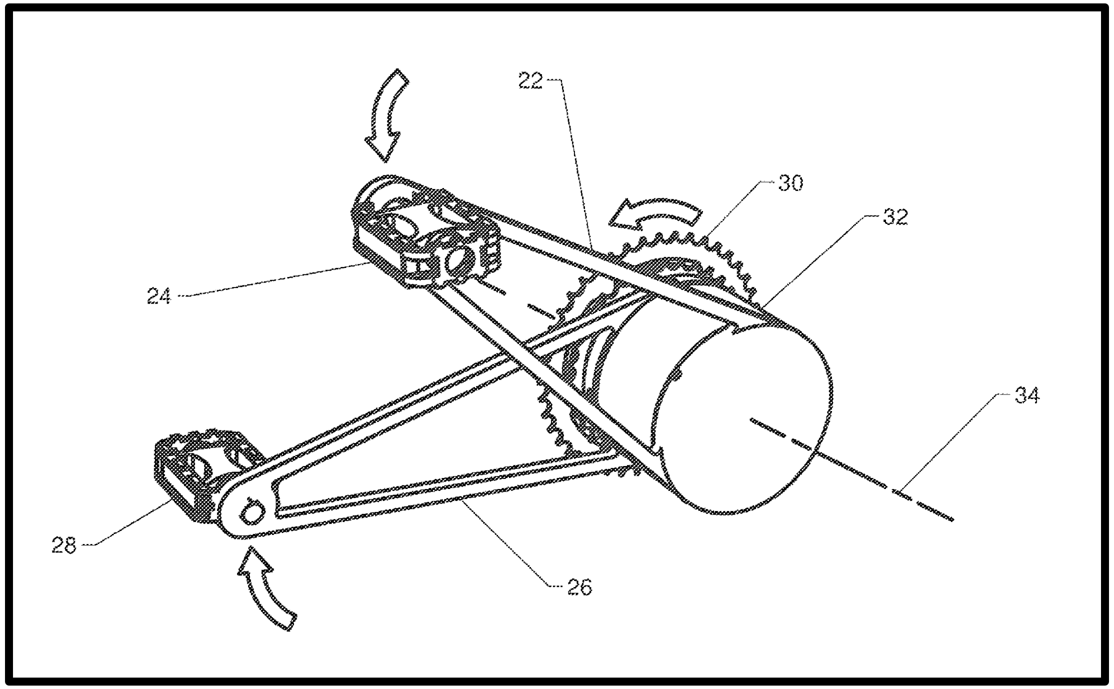

Figure 2. RLT patent drawing by Gordon Hansen, AICP.

Background

- Increasing popularity of bicycles in flatland cities for transportation.
- Cycling motion puts undesirable stresses on rider’s joints.
- The RLT design is an alternative way of pedaling.

Previous Work

- Team 09 is the third team assigned to the RLT project sponsored by Gordon Hansen.
- Previous teams have developed versions of the RLT, however, Team 09 was tasked with new design parameters for the RLT.
- The two main new design parameters include the addition of sprag clutches as well as 14 inch long crank arms.

Video 1. Previous Design RLT [1].

Target Summary and Benchmark Tests

Daniel Dudley

What are Sprag Clutches?

- One-direction drivable clutch
- Can be driven from either race
- Several applications
  - Helicopters
  - Motorcycles

Driven Race

Driving Race

Video 2. Sprag Clutch Operation [2].

Target Summary

Addition of Sprag Clutches

- *Purpose:* The addition of sprag clutches to the RLT design increases the amount of torque the system can handle.
    - *Design Considerations:* Shaft size, RLT housing dimensions, shear force analysis.
    - *Design Plans:* Obtain sprag clutches from distributor and begin sizing shafts. Analyze shear stress on the shaft with the added sprag clutches.

Improvement in Gear Meshing

- *Purpose:* More effective gear meshing would lengthen the life of the bevel and pinion gears as well as increase the power output of the RLT.
    - *Design Considerations:* Gear ratios, safety factors, bearing fittings in RLT housing, stress analysis on gear teeth.
    - *Design Plans:* Produce CAD models with new design and run motion tests via CAD software. Design and manufacture new RLT with better gear meshing.

Target Summary

Efficiency Increase by 10%

- *Purpose:* An efficiency increase by 10% would lead to further research and development and potentially a new manufactured product.
  - *Design Considerations:* Smooth RLT and sprag clutch interaction.
  - *Design Plans:* Test power generation of traditional bicycle drive train designs and the RLT design. Compare power generation between the two and determine the efficiency increase.

Longer Crank Arms

- *Purpose:* Longer crank arms will create a larger moment and lead to more power production.
  - *Design Considerations:* Crank arm material, crank arm shape design, shear stress analysis, user compatibility.
  - *Design Plans:* Develop CAD models of crank arms, run stress analysis tests via CAD, implement best design.

Traditional Bicycle Tests

2 Traditional-style bicycles

Gear ratios: 2.35:1
2.79:1

Percent Change in Power relative to different gear ratios

$$\Delta P = \left(\frac{g_r}{g} - 1\right) * 100\% \quad [1]$$

18.7% power change in test bicycles

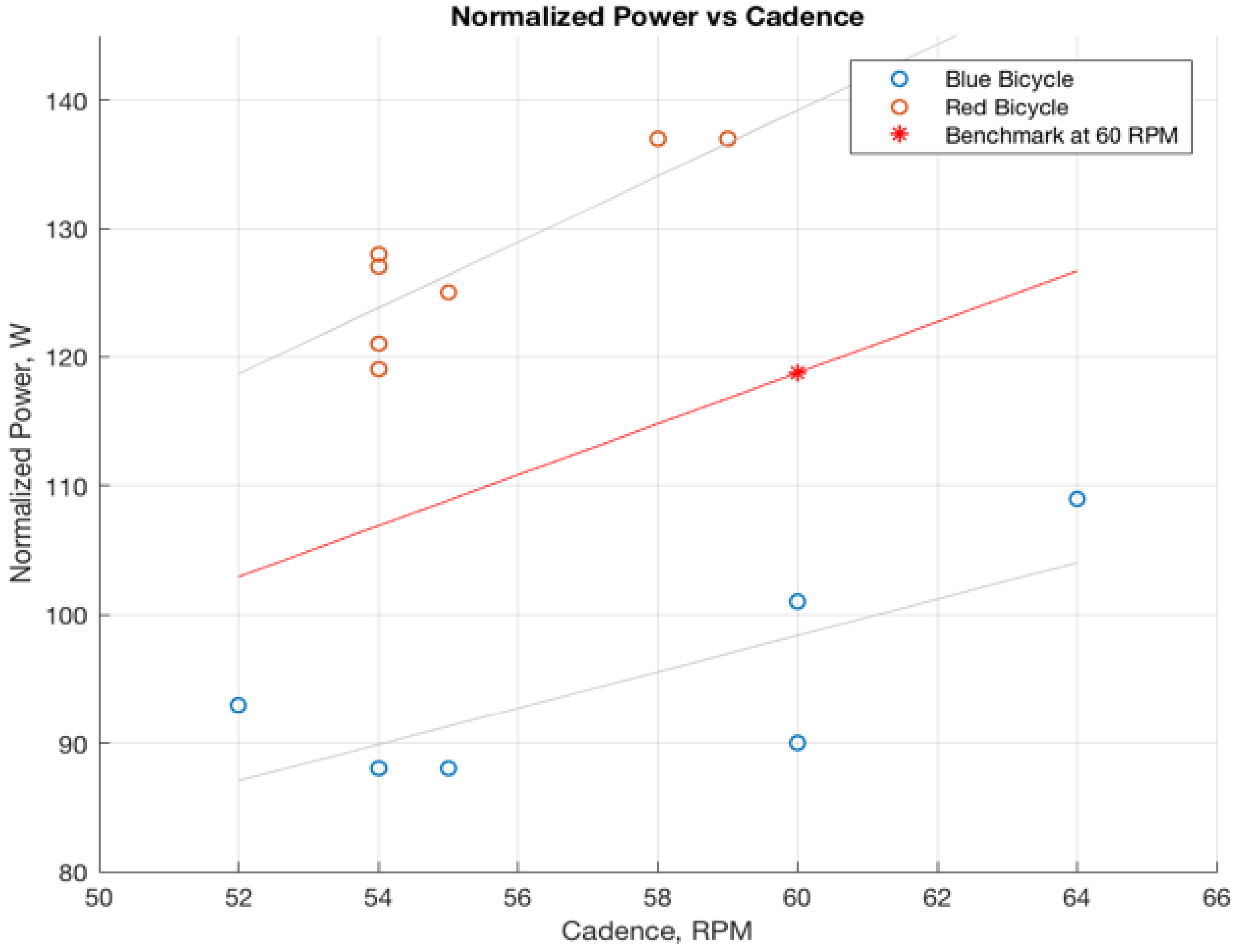

Figure 3. Linear Regression Line of Power vs Cadence

Benchmark Tests and Targets

Cadence (RPM)	Average Measured Normalized Power (W)	Target Normalized Power (W)	Testing Conditions
60	118.8	130.7	Warm Up: 15s Interval: 60s
Cadence (RPM)	**Heart Rate (BPM)**	**Target Heart Rate (BPM)**	**Testing Conditions**
60	67	60	Warm Up: 15s Interval: 60s Rest: 60s
90	112	101	Warm Up: 15s Interval: 30s Rest: 60s

Concept Generation

Samuel Evan Grambling

Concept Generation: Systems

- Drive Shaft

- Crank Arm

- Bevel Gear and Hub Assembly

System: Drive Shaft

Concept #1

- Square Cut: 17 mm x 17 mm
- Outer Diameter: 25 mm
- Inner Diameter: 10 mm
- Hollow shaft

Concept #2

- ½ inch Hexagonal Cut allows use of original chain wheel sprocket
- Outer Diameter: 25 mm
- Solid shaft

Figure 4. Drive Shaft Concept #1.

Figure 5. Drive Shaft Concept #2.

System: Crank Arm

Concept #1

- Design of previous year's RLT
- Power production was non-substantial compared to a traditional bicycle
- Linear profile is not attractive to client

Concept #2

- 14-inch length satisfies product requirement
- Tapered profile is appealing to client and closely resembles patent

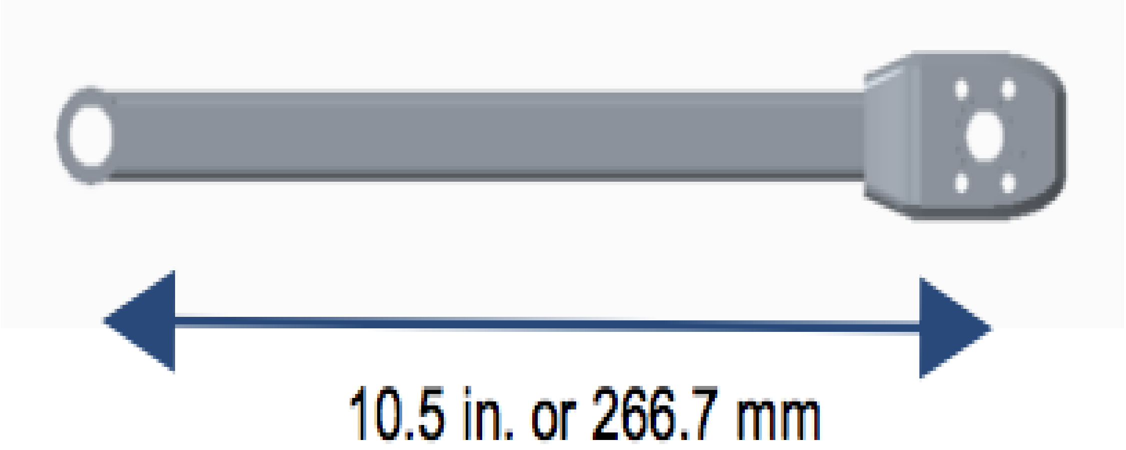

Figure 6. 10.5-inch Linear Profile Crank

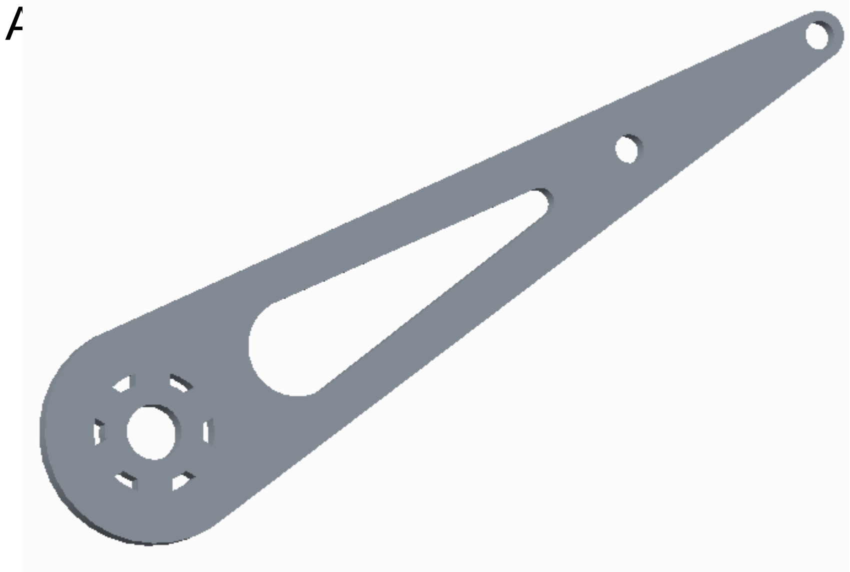

Figure 7. 14-inch Tapered Profile Crank Arm.

System: Bevel Gear Hub Ass

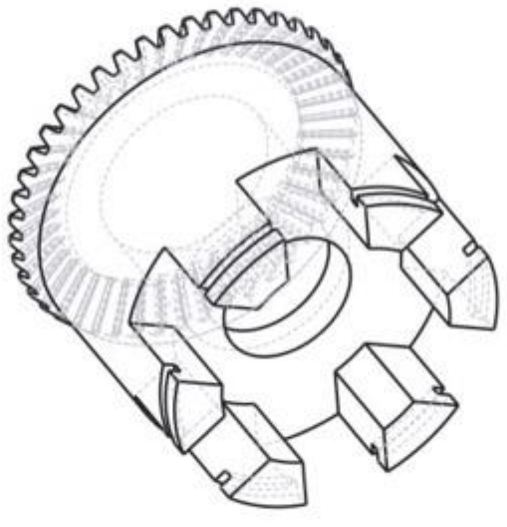

Figure 8. One-Piece Bevel H

Concept #1

- Attractive connection between hub and back of gear face
- $600 per assembly from KHK-USA
- 6 week lead time

Concept #2

- Separate bevel gear and steel cylinder secured together
- 4 welds
- Bevel gears already in-house
- Made at COE Machine Shop

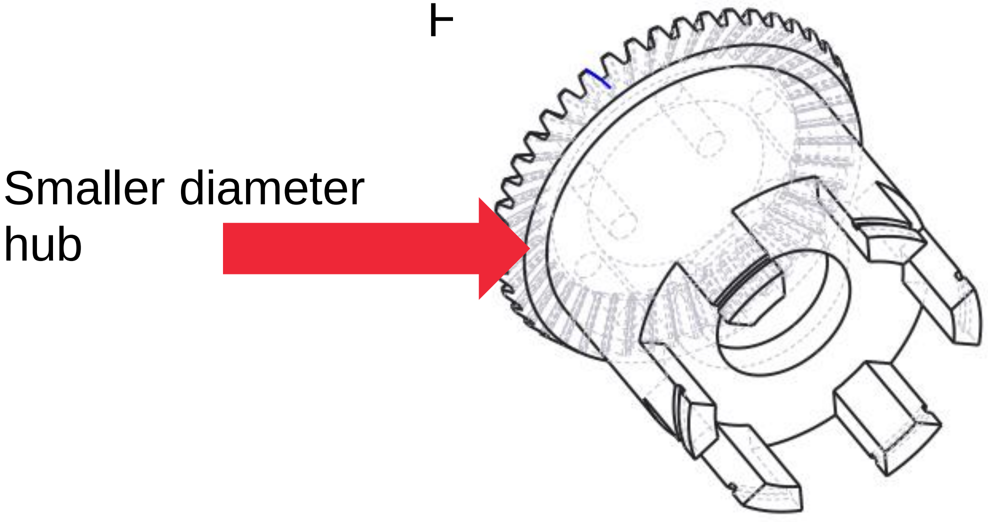

Figure 9. Two-Piece Bevel Hub.

Design Challenges and Budget

Grant Parker

Design Problems Encountered and Solutions

Problem	Price and lead time for the one-piece bevel hub was not practical
Solution	New two-piece bevel hub design was used
Problem	Aluminum housing potentially rotating around in mounting shell
Solution	Set screws were used to prevent housing from rotating around
Problem	Unable to acquire proper size bearings for pinion gears
Solution	Ordered smaller bearings and turned down pinion gear hub diameters
Problem	Proper number of sprag clutches to be used
Solution	2 on in each bevel hub (4 total) based on torque load and how wide the RLT would be

One Piece Bevel Gear Hub Budget

Item No.	Description	Item	Item Number	Distributor	Unit Price	Quantity	Total Price	Notes
1	Crank Arms	2024 Aluminum Sheet	9040K432	McMaster Carr	$267.88	1	$267.88	12”x24”0.5”
2	Sprag Clutches	Sprag Clutches	FE433M	Houston Bearing & Supply	$197.40	4	$789.60	D=33mm d=25mm
3	Drive Shaft	4140 Alloy Steel Rod	5836T295	McMaster Carr	$27.55	1	$27.55	Tol=-0.013mm to 0mm
4	Housing Bearings	Pinion Gear Bearings	5972K84	McMaster Carr	$9.62	4	$38.48	D=17mm
5	Sprag Snap Rings	Internal Snap Rings	98394A467	McMaster Carr	$3.10	2	$6.20	OD=34mm
6	Crank Arm Snap Rings	External Snap Rings	91590A152	McMaster Carr	$5.44	2	$10.88	ID=25mm
7	Drive Shaft Snap Rings	4140 Alloy Steel Sheet	4473T32	McMaster Carr	$8.82	1	$8.82	D=25mm (5 pack)
8	Housing	Aluminum Sock	86985K44	McMaster Carr	$145.39	1	$145.39	D4”xL6”
9	Outer Race Bearings	Bevel Gear Bearings	6656K21	McMaster Carr	$336.84	2	$673.68	ID=63.67mm for no lip gear
10	Outer Race Gear	Bevel Gears	Custom	KHK USA	$598.60	2	$1,197.20	Custom gears for sprag clutches

Total Cost	**$3,165.68**
Remainder	**$(1,165.68)**

Two Piece Bevel Gear Hub Budget

Item No.	Description	Item	Item Number	Distributor	Unit Price	Quantity	Total Price	Notes
1	Crank Arms	2024 Aluminum Sheet	9040K432	McMaster Carr	$267.88	1	$267.88	12”x24”0.5”
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8	Housing	Aluminum Sock	86985K44	McMaster Carr	$145.39	1	$145.39	D4”xL6”
9	Outer Race Bearings	Bevel Gear Bearings	61811-2RS1	VXB Bearings	$24.95	4	$99.80	OD=72mm ID=55mm
10	Outer Race Gear	Bevel Gears	In Stock	KHK USA	N/A	2	N/A	In Stock
11	Outer Race Hub	Rod	6[illegible]	[illegible]	[illegible]30	1	$55.30	D2.5”x12”
11*	Outer Race Hub	Rod	8[illegible]	[illegible]	[illegible].81	1	$49.81	D2.5”x12” to replace
12	Alignment Pins	Alignment Pins	8472A11	McMaster Carr	$2.36	6	$14.16	To align bevel hubs

Total Cost	**$1,513.87**
Remainder	**$486.13**

Concept Selection and Complications

Iain Marsh

Design Concepts

Concept #1

- 14-inch linear profile crank arm
- One-piece bevel gear hub
- Hollow drive shaft with square cut for sprocket attachment

Concept #2

- 14-inch tapered profile crank arm
- Two-piece bevel gear hub
- Solid drive shaft with hexagonal cut for sprocket attachment

Design Matrix

Selection Criteria	Traditional Bicycle	RLT Concept #1	RLT Concept #2
Power generation	Datum	+	+
Serviceability		+	+
Ease on joints		+	+
Part manufacturing ease		-	+
Ability to use parts from last year's design		-	+
Future reverse capability		+	-
# of Pluses		**4**	**5**
# of Minuses		**3**	**2**

Concept Selection

- 14-inch tapered profile crank arms

  Satisfies customer needs of 14-inch crank arm and aesthetic design

- Two-piece bevel gear hub

  Cheaper alternative within our time constraint

- Solid drive shaft with hexagonal cut

  Allows us to use previous team's chain wheel sprocket

Sprag Clutch Selection

F_{mean} = 336.8 N (Kautz)

SF = 1.5

$T_{required}$ = 179.6 Nm

FE-433M Sprag Clutch

N = 2 sprag clutches per side

$$T_{transferable} = 0.9 * N * T_{nominal}$$

$T_{transferable}$ = 252 Nm > 179.6 Nm ✓

Figure 10. FE-400M Series Sprag Clutch

Inner Diameter: 25 mm
Outer Diameter: 33 mm
$T_{nominal}$ = 140 Nm

Manufacturer: GMN Bearing USA Ltd.
Distributor: Houston Bearing and Supp

Evolution of Design

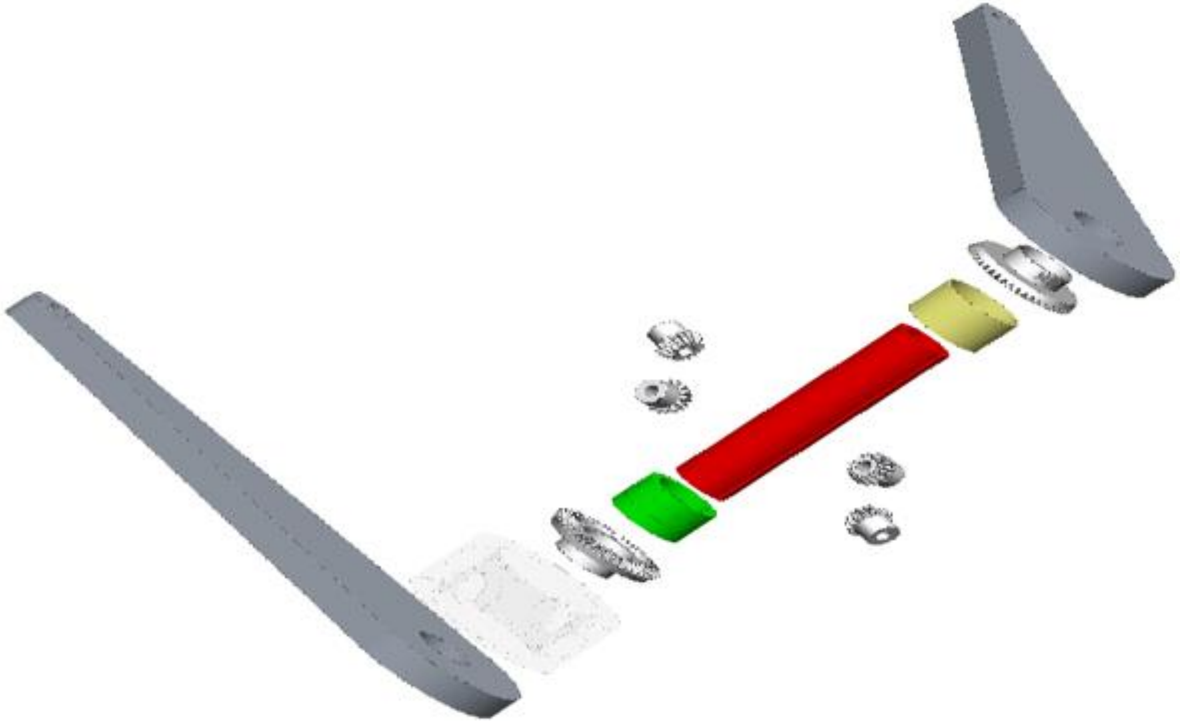


Figure 11. First Design Iteration.

First design iteration of RLT

- Shows 3 sprag clutches per side
- 4 pinion gears follow design of client's patent
- 4 gears allow for easier manufacture of housing

Missing:

- Bearings
- Splines

Final Design

- 2 sprag clutches per side
- 2 bevel hub bearings per side
- 6 splines on bevel hubs for crank arm attachments

Color Code:
Green – bearing spacers
Blue – bevel gear bearings

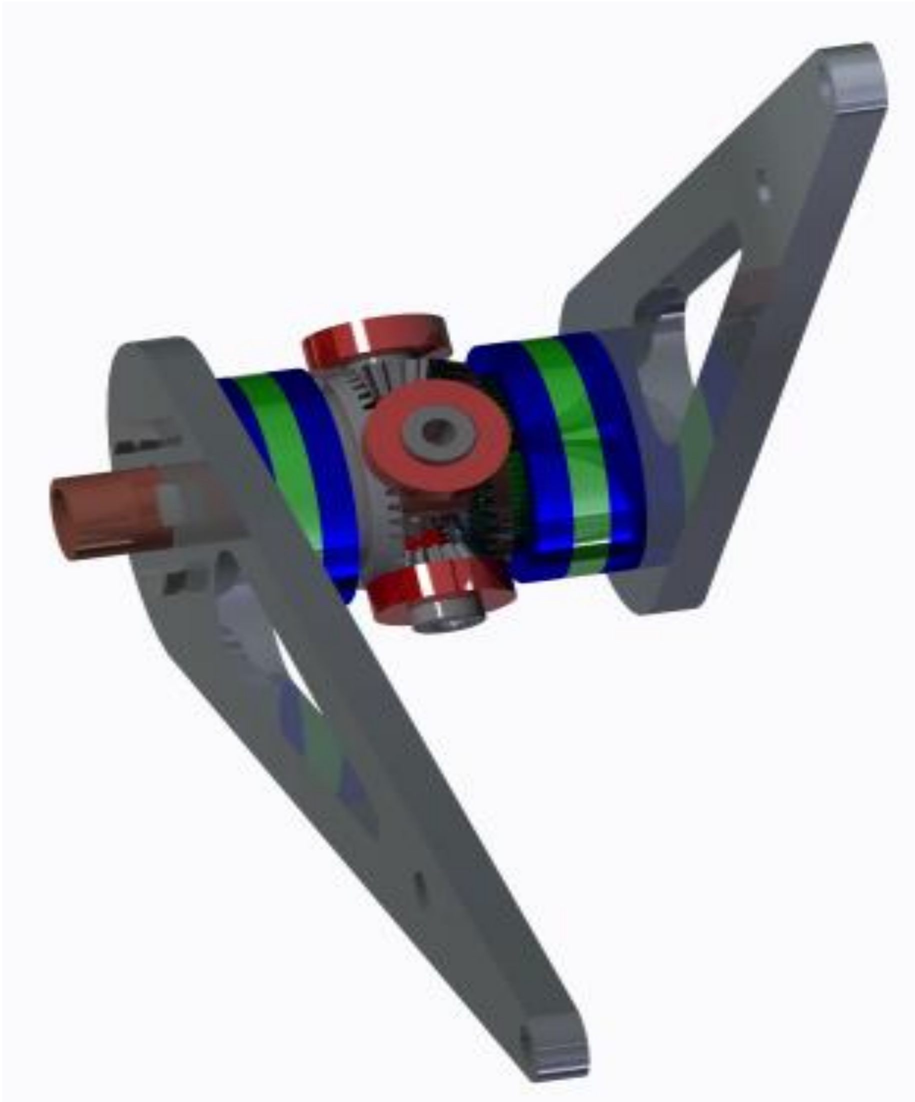


Figure 12. Final Design. (Housing and Shell are Hidden).

Pictures

Figure 13. RLT in Vertical Orientation as it will be for Team 20.

Figure 14. RLT Mounted

Complications

Attempted to test on the Kinetic Road Machine.

RLT produced a slow speed with test bicycle.

RLT failed.

- Improper gear meshing.
- Crank arms slipped and did not return opposite crank arm.
- Without return mechanism, testing became impossible.

Figure 15. Kinetic Road Machine Testing Rig.

Future Work

- Investigate source of problem.
- Fix the problem.
- Create alternative design if necessary.
- Lower the gear ratio for faster speeds.

References

- [Senior Design Team 08]. *Testing of the HANSCycle*. [Video File]. Retrieved from https://ww2.eng.famu.fsu.edu/me/senior_design/2017/team08/
- [Renold]. (2012, May 28). *Renold Sprag Clutch.* [Video File]. Retrieved from https://www.youtube.com/watch?v=Fsp3fm4KHs0
- Kautz, S. A., M. E. Feltner, et al. (1991). "The Pedaling Technique of Elite Endurance Cyclists: Changes with Increasing Workload at Constant Cadence." International Journal of Sport Biomechanics **7**(1): 29-53.

Thank You!

Are There Any Questions?

Additional Slides

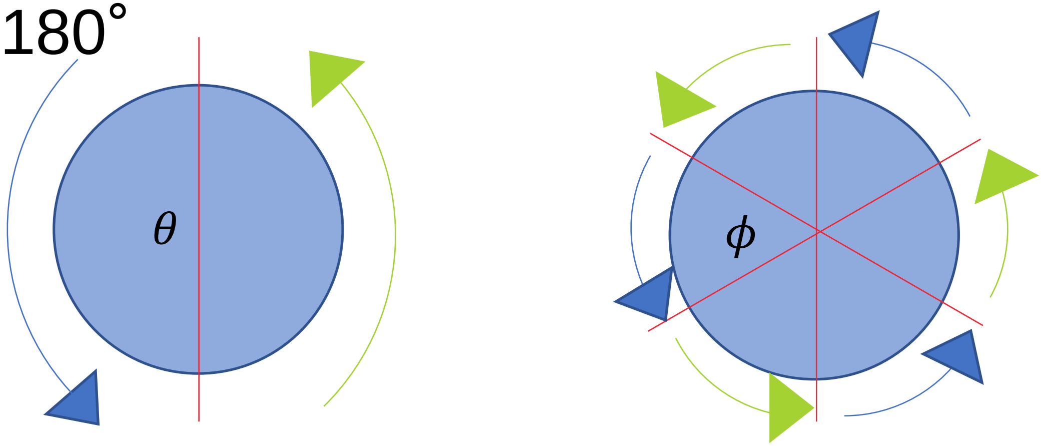
Neutral Position

Figure 17. RLT lying in “neutral position”

Chord Length

Red line – 14 inch chord length
Equal to twice the length of traditional bicycle crank arms
Green lines – 14 inch crank arm length

$\phi = 60^\circ$
3 times as small as a traditional bicycle's crank arm stroke angle of 180°



$\theta = 180^\circ$
$\phi = 60^\circ$

Speed Calculations

- Target Cadence: 60 RPM
- RLT Equivalent Shaft Angular Velocity: 20 RPM

- Gear ratio 2.79:1 (39/14)
- 27” x 1 ¼” tire
- Circumference: 84.82”

$$\omega_{rearwheel} = Gear\ Ratio * \omega_{cadence}$$

Traditional Bicycle

At target cadence, speed achieved is 13.45 MPH

RLT

At target cadence, speed achieved is 4.48 MPH

With a recommended low gear ratio of 4.82:1 (53/11)

Speed achieved is 7.74 MPH

"Dead Spots"

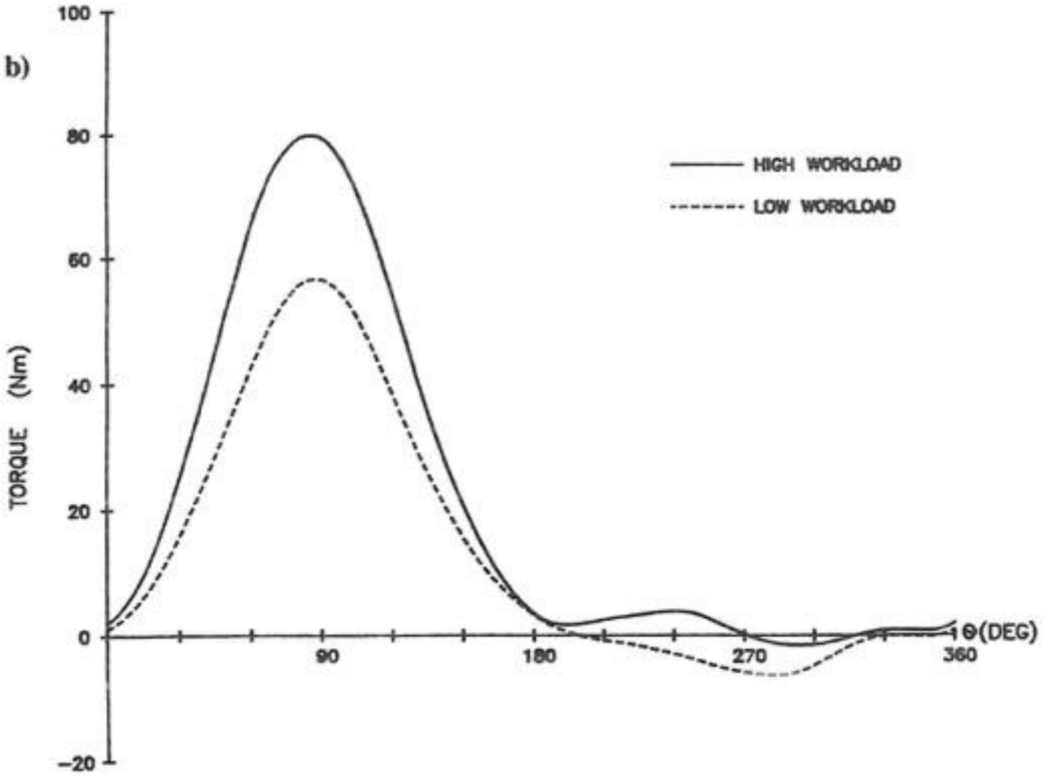


Figure 17. Torque generated by one crank arm over 1 revolution of a traditional bicycle (Kautz).

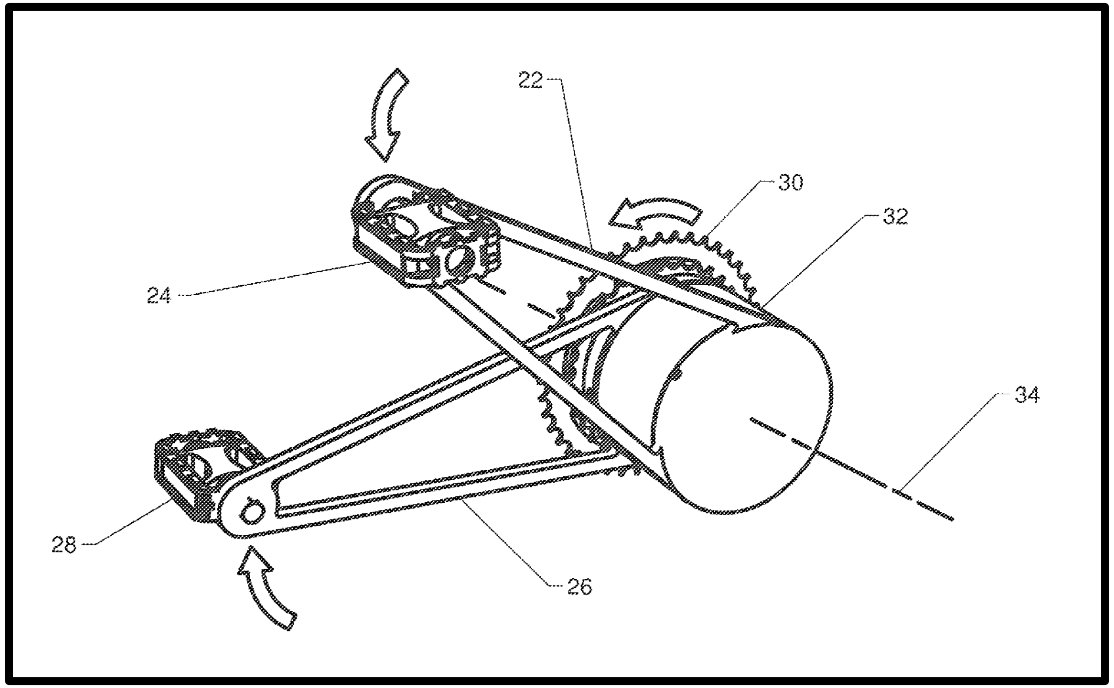


Figure 2.