

Modified Bicycle Motion

Background Report

Team 19:

Fahad Alajmi

Matthew Palmer

K. Zoe Lucke

Alex Lawson

Basem Alghamdi

September 2016

ME 476C – Section 1

Project Sponsor: Dr. Raab

Faculty Advisor: Dr. Trevas and Dr. Oman

Instructor: Dr. Trevas

Table of Contents

1	BACKGROUND	3
1.1	Introduction.....	3
1.2	Project Description.....	3
1.3	Original System	3
1.3.1	Original System Structure	4
1.3.2	Original System Operation.....	4
1.3.3	Original System Performance	4
1.3.4	Original System Deficiencies.....	4
2	REQUIREMENTS	5
2.1	Customer Requirements (CRs).....	5
2.2	House of Quality (HoQ)	6
3	EXISTING DESIGNS	6
3.1	Design Research	6
3.2	System Level.....	7
3.2.1	Existing Design #1: Shortened Crank Arm (Orthopedal)	7
3.2.2	Existing Design #2: Retractable/Extendable Crank Arm Patent	7
3.2.3	Existing Design #3: CrankTip Pedal	8
3.2.4	Existing Design #4: Kneesavers	8
3.2.5	Existing Design #5: Pivoting Crank Arm (Duke University)	9
3.2.6	Existing Design #6: Rotor Q-Rings.....	9
3.3	Subsystem Level	10
3.3.1	Subsystem #1: Crankset.....	10
3.3.2	Subsystem #2: Chains	11
3.3.3	Subsystem #3: Cassettes.....	12

List of Figures

FIGURE 1: BICYCLE DIAGRAM	4
FIGURE 2: ORTHOPEDAL CRANK ARM	7
FIGURE 3: EXTENDABLE/RETRACTABLE CRANK ARM	7
FIGURE 4: PEDAL PATH FOR EXTENDABLE/RETRACTABLE CRANK ARM	7
FIGURE 5: CRANKTIP PEDAL PATH VS. STANDARD PEDAL PATH	8
FIGURE 6: PEDAL WITHOUT KNEESAVERS VS. PEDAL WITH KNEESAVERS	8
FIGURE 7: PIVOTING CRANK ARM	9
FIGURE 8: ELLIPTICAL ROTOR Q-RING CHAIN RING	9
FIGURE 9: SHIMANO ULTEGRA CRANKSET	10
FIGURE 10: SHIMANO XTR TRAIL CRANKSET (2X)	10
FIGURE 11: CAMPAGNOLO SUPER RECORD CRANKSET	11
FIGURE 12: SRAM XX1 EAGLE CHAIN	11
FIGURE 13: SHIMANO DURA-ACE CHAIN	11
FIGURE 14: MUC-OFF NANO CHAIN	12
FIGURE 15: SRAM XX1 EAGLE CASSETTE	12
FIGURE 16: CAMPAGNOLO SUPER RECORD CASSETTE	13
FIGURE 17: SHIMANO ULTEGRA CASSETTE	13

1 BACKGROUND

1.1 Introduction

This project is about modifying a bicycle to limit range of motion in the knee joint. The project was presented by our client Dr. Scot Raab, an assistant professor of Athletic Training at Northern Arizona University. Dr. Raab has suffered a knee injury that resulted in his meniscus being removed. This severely limits his range of motion in his knee making it difficult to ride a bicycle. Although there are products that accomplish this, they tend to limit torque output, making it difficult for the rider to go uphill and attain high speeds. The objective of this project is to design a device for a standard bicycle that will limit range of motion in the knee with minimal torque loss.

1.2 Project Description

Following is the original project description provided by the sponsor:

“Modified Bicycle Motion”

Problem: Cyclist (recreational or competitive) that suffer knee injuries limiting ROM (Range of Motion) must give up cycling because the top of the pedal stroke causes extreme flexion of the knee. This results in abnormal forces across the knee joint and the patellar femoral articulation causing discomfort.

Current attempted solutions:

1. Raise seat height but to go to high prevents appropriate alignment at the bottom of the pedal stroke and may result in rocking left and right on the saddle resulting in low back issues or soft tissue damage to the Perineum (area of soft tissue between what cyclist refer to as the sit bones or the ischium's)
2. Shorten the crank arm of the pedal but this decreases torque and speed available to the cyclist or ability to climb inclines.

Objective: Protect ROM (limit it) and allow cyclist to produce maximal torque using current gears available to cyclist via front or rear chain rings

That last part almost allows the team to invent a new set of gears but that requires thinner, thicker, longer, or shorter chains, etc. As you add rings to the gears your chain must be thinner to fit between the gears or the hub needs to get wider and that create s wider bike, etc. The objective of this project is to limit the amount of drastic modifications to existing bikes, but provide a smaller ROM for the rider.

Create a modification that can be applied to (one size, multiple sizes?) standard bikes to modify the motion of the cyclist so their knees do not bend beyond 90 degrees.”

1.3 Original System

This project involves the modified design of a standard two-wheel bicycle design. A standard bicycle is composed of a frame, fork, wheels, drivetrain, handlebars, brakes, and a saddle.

1.3.1 Original System Structure

A standard bicycle frame design consists of a double diamond design and features a fork that is placed in the head tube of the frame. Bicycles can be made from steel, aluminum, titanium, or carbon fiber. Most bicycle components are made of either aluminum or carbon fiber depending on the price level of the build. The figure below is of a standard road bike and has all of the components labeled.



Figure 1: Bicycle Diagram

1.3.2 Original System Operation

A standard bicycle converts mechanical energy from the user into translational motion. This is performed via the drivetrain system containing a set of chain-driven gears. This set of gears is put in motion by the user through the pedals. The bicycle's drivetrain contains a set of adjustable gears, allowing the user to shift to a different gear ratio depending on terrain. This system is cable-operated, and adjusted manually by the user via a switch on the handlebars. This same handlebar system contains the controls for the cable-operated brakes and steering functionality [1].

1.3.3 Original System Performance

The weight of our client's road bicycle is 19 lb. and the general modern mid-range road bike weighs around 17-18 lbs. Our client generally averages about 15-16 mph on his bike rides, but can fluctuate due to head or tail winds and the amount of climbing or descent included in the ride.

1.3.4 Original System Deficiencies

The current system forces the user to bend their knee at an angle less than 90 degrees at the top of the pedal stroke, causing pain for a rider with flexural knee issues. It is currently believed that a combination of the pedal crank arm length and seat height are the primary cause of this issue. Table 1 tabulates a list of commonly manufactured crank arm lengths.

Table 1: Commonly Manufactured Lengths of Crank Arms

Crank Arm Length (mm)
165
170
172.5
175

2 REQUIREMENTS

2.1 Customer Requirements (CRs)

Our customer requirements are rated on a scale of 1 to 5, 1 being the least important. Our customer requirements are durability (4), retrofittability (5), low weight (3), maximum torque (5), low cost (3), safety (5), and aesthetics (2).

We rated retrofittability as a 5 because our client wants a device that he can attach to his own bicycle instead of having to replace his entire bicycle. We rated maximum torque as a 5 because this is one of our main objectives and what will distinguish our design from existing designs. We rated safety as a 5 due to our engineering code ethics. We rated durability as a 4 because we desire for our design to not break in a crash and for it to withstand uneven terrain. We rated low weight as a 3 because low weight is desirable and convenient, but not necessary. We rated low cost as a 3 because we would like our product to be accessible to more cyclists. Finally, we rated aesthetics as a 2 because we value function over form.

(Remainder of Page Purposefully Left Blank)

2.2 House of Quality (HoQ)

Customer Requirement	Weight	Engineering Requirement							
Durable	4								
Retrofittable	5								
Low weight	3								
Max Torque	5								
Low cost	3								
Safe	5								
Aesthetics	2								
Absolute Technical Importance (ATI)									
Relative Technical Importance (RTI)									
Target(s), with Tolerance(s)									
Testing Procedure (TP#)									
Design Link (DL#)									

Approval (print name, sign, and date):

Team member 1: Alex Lawson, AL, 9/23/2016

Team member 2: Basem Alghamdi, BA, 9/23/2016

Team member 3: Fahad Alajmi, FA, 9/23/2016

Team member 4: Kathryn Lucke, KL, 9/23/2016

Team member 5: Matthew Palme, MP, 9/23/2016

Client Approval: Scot.Raab

3 EXISTING DESIGNS

3.1 Design Research

We researched many different existing designs that claim to help reduce forces on the knee joint and/or reduce the knee's range of motion, or the knee angle. We conducted web searches and wrote literature reviews on the existing designs we found, whether in the form of an article, a patent, or a product's website. The existing designs found are outlined and compared to customer requirements in Section 3.2.

3.2 System Level

The following section describes existing designs found and compares it to customer requirements and to the other existing designs.

3.2.1 Existing Design #1: Shortened Crank Arm (Orthopedal)

This design is a product currently on the market, called the Orthopedal. The Orthopedal is a small metal device that is attached onto a bike crank arm illustrated in Figure 1. It has four different slots along the crank arm to insert the pedal, thus adjusting the crank arm length. The shortened crank arm length results in a limited range of motion, causing reduced forces on the knee joint. However, it reduces torque capacity causing increased difficulty in biking uphill and reduced maximum speed. [2]



Figure 2: Orthopedal Crank Arm

3.2.2 Existing Design #2: Retractable/Extendable Crank Arm Patent

This design is a for a US patented retractable crank set for a bicycle. This crank set, illustrated in Figure 3, has a crank arm that extends and retracts depending on position. The crank shaft will be in the retracted phase at the top of the pedal stroke which will reduce the effects of patellar femoral articulation. Then the crank shaft will extend along the front side of the stroke which results in more produced torque. The crank path is illustrated in Figure 4 in orbital L. This design is similar, but is more desirable in terms of torque than the Orthopedal design described in 3.2.1. However, this design cannot be easily retrofitted onto different bikes, like the Orthopedal. [3]

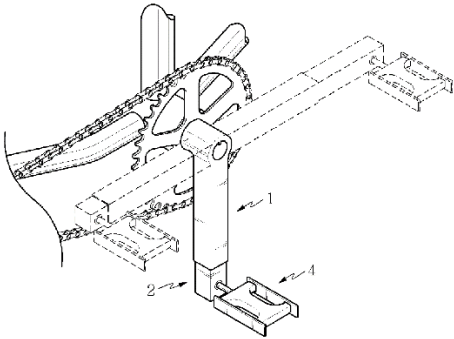


Figure 3: Extendable/Retractable Crank Arm

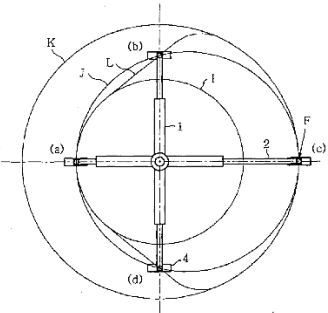


Figure 4: Pedal Path for Extentable/Retractable Crank Arm

3.2.3 Existing Design #3: CrankTip Pedal

This design is a device that is currently available on the market and is attached onto the pedal of a standard bicycle. The device has a dual swing-arm mechanism that moves the pedal in front of the end of the crank arm along the front of the pedal stroke causing increased torque. The crank arm shortens along the back of the stroke to reduce range of motion experienced by the knee at the top of the stroke. The path of the pedal for a CrankTip Pedal is compared to the pedal path of a standard pedal in Figure 5. This design can be easily retrofitted onto any bike and has a more desirable torque than the plain shortened crank arm design. However, it's high in cost. [4]

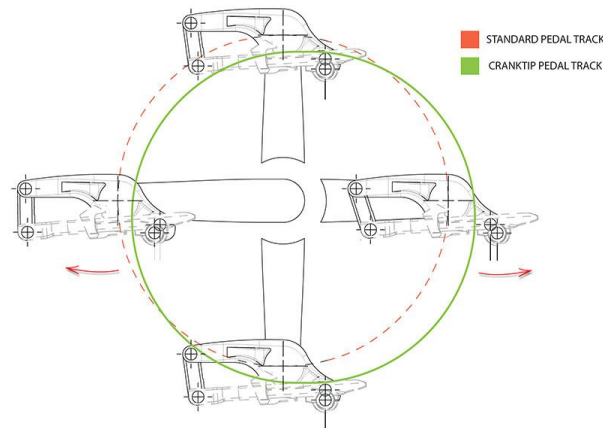


Figure 5: CrankTip Pedal Path vs. Standard Pedal Path

3.2.4 Existing Design #4: Kneesavers

This design is a small device that is currently on the market, called Kneesavers. It extends the pedals outward from the bicycle, as seen in Figure 6, reducing forces on the knee joint. This design changes the forces acting on the knee, however it does not affect the knee angle throughout the pedal stroke. [5]



Figure 6: Pedal without Kneesavers vs. Pedal with Kneesavers

3.2.5 Existing Design #5: Pivoting Crank Arm (Duke University)

This design was created by a group of students at Duke University. They were tasked with modifying a bicycle so that their client, who has limited range of motion in her left knee, can continue to bike as a hobby. Their design consists of a pivoting crank arm that pivots to shorten the crank arm, reducing the range of motion in the knee and making it more comfortable for the injured rider. This design is pictured in Figure 7 below. This design is limited due to its poor torque output which produces the same problem as the Orthopedal and the shortened crank arm. It reduces the maximum speed attainable and the ability to go uphill comfortably. [6]



Figure 7: Pivoting Crank Arm

3.2.6 Existing Design #6: Rotor Q-Rings

This design is of chain rings that are applied to standard cranks. The chain rings are elliptical in shape, shown in Figure 8, and reduce the patellar force on the knee at the top of the pedal stroke by making the chain ring size smaller. The chain ring becomes bigger along the front of the pedal stroke where the most power is produced, thus creating more torque. Although this does not directly affect the range of motion in the knee, it can be combined with a shortened crank arm to limit range of motion and increase torque output. [7]



Figure 8: Elliptical Rotor Q-Ring Chain Ring

3.3 Subsystem Level

The main function of this project is to propel the rider of the bicycle forward through the drivetrain of the bicycle. Firstly, the user applies force through the legs on to the pedals, which are attached to the end of crankset. The force from the crankset is applied to chain rings that causes them to rotate in a clockwise motion, the teeth on the chain ring pull the chain in the same direction. The chain will pull rotate the cassette (gear set located at the back of the bike) and the rear wheel in the clockwise direction. The content of the section below will be discussing the existing designs for (1) cranksets, (2) chains, and (3) cassettes.

3.3.1 Subsystem #1: Crankset

Force is applied through the pedals on the crank arms make them act as a lever. The chain rings are fixed to the crankset and rotate with the cranks in a clockwise motion.

3.3.1.1 Existing Design #1: Shimano Ultegra Crankset

The Shimano Ultegra road bike crankset features a four arm spider design for mounting two chain rings, capable of handling a variety of different chain ring sets, chain guide on chain rings to reduce chain dropping, made of aluminum, and works for 11 speed group sets. This product relates to our customer requirements by having optimal stiffness for power/torque transfer, durable, aesthetics, low weight (765g), and reasonably priced. [8]



Figure 9: Shimano Ultegra Crankset

3.3.1.2 Existing Design #2: Shimano XTR Trail Crankset

The Shimano XTR mountain bike crankset features three different four arm spider designs for mounting 1-3 chain rings (1X, 2X, or 3X), made for 11 speed group sets, and made of aluminum. This product relates to our customer requirements by providing optimal power transfer through the cranks, low weight (1X – 583g, 2X – 630g, and 3X – 656g), durable, aesthetics, and safe. [9]



Figure 10: Shimano XTR Trail Crankset (2X)

3.3.1.3 Existing Design #3: Campagnolo Super Record Crankset

The Campagnolo Super Record road bike crankset features a four arm spider design for mounting the two chain rings, step-up system on chain rings to enhance shifting performance, carbon construction, compatible with 11 speed group sets, and a simple assembly for ease of maintenance. This crankset relates the following customer requirements durable, aesthetics, no torque/power loss, and low weight (603g). [10]



Figure 11: Campagnolo Super Record Crankset

3.3.2 Subsystem #2: Chains

The chains are held in place by the toothed gears that are the chain rings and cassettes. The chain will carry the clockwise rotation of the crankset which will move the cassette and rear wheel.

3.3.2.1 Existing Design #1: Sram XX1 Eagle Chain

This Sram XX1 mountain bike chain features quiet operation, no interior square edges, increased wear resistance over previous iterations, hollow pins, and works for 12 speed group sets. This chain relates to the following customer requirements of being durable, low weight from the hollow pins, and aesthetics (gold colored). [11]



Figure 12: Sram XX1 Eagle Chain

3.3.2.2 Existing Design #2: Shimano Dura-Ace Chain

The Shimano Dura-Ace chain features hollow pins, a PTFE coating to help increase the wear resistance of the chain, and is compatible with 11 speed group sets. This product relates to our customer requirements by being low weight (243g) and having increased durability. [12]



Figure 13: Shimano Dura-Ace Chain

3.3.2.3 Existing Design #3: Muc-Off Nano Chain

The Nano Chain is a chain is not made by a bicycle component company, however it is made by company that makes chain lubricants. A chain can be chosen for the drivetrain of the purchaser's choice. The chain is hand treated and has a special lubricant applied to it to reduce drivetrain resistance and improve the chain's weatherproof capabilities. This chain meets the customer requirements of durability and improves the torque output efficiency of the drivetrain. [13]



Figure 14: Muc-Off Nano Chain

3.3.3 Subsystem #3: Cassettes

The cassette the group of gears located at the rear of the bike and is attached to the rear wheel. The motion transferred from the chain causes the cassette to rotate clockwise and rotate the rear wheel.

3.3.3.1 Existing Design #1: Sram XX1 Eagle Cassette

Sram's XX1 Eagle Cassette is one of the only commercially available cassettes that has 12 cogs or gears on it, has a wide range of gears that are optimal for mountain biking (10-50 teeth), one of the strongest cassettes available, and has the smallest tooth available which has 10 teeth in it. This product meets the customer requirements of durability, maximum torque output from the 10 tooth cog, and aesthetics (gold colored). [14]



Figure 15: Sram XX1 Eagle Cassette

3.3.3.2 Existing Design #2: Campagnolo Super Record Cassette

The Campagnolo Super Record cassette features six titanium sprockets, has a nickel-chrome surface treatment to increase the life of the cassette, and the teeth are designed to provide maximum power transmission to the rear wheel. This design meets the customer requirements of maximum torque, durability, and lightweight (177g). [15]



Figure 16: Campagnolo Super Record Cassette

3.3.3.3 Existing Design #3: Shimano Ultegra Cassette

The Shimano Ultegra cassette features the availability to have a wide range of gears available for road cycling ranging from 11 to 32 teeth, which is better for climbing. This cassette aligns with the torque because an 11 is the general industry standard for the smallest number of cassette teeth and this design is reasonably priced. [16]



Figure 17: Shimano Ultegra Cassette

REFERENCES

- [1] Bicycle science - how bikes work and the physics behind them. (2016). *Explain that Stuff*. [Online]. Available: <http://www.explainthatstuff.com/bicycles.html> (URL).
- [2] Orthopedal – Knee Rehabilitation. (N.D.). Orthopedal. [Online]. Available: <http://www.orthopedal.com> (URL).
- [3] K. H. Lee, “Retractable/extendable crank using a cylindrical cam, an end cam, or a swash plate cam, and bicycle using the same,” U.S. Patent 20110121536 A1. May 26, 2011.
- [4] Cranktip: How It Works. (N. D.). Cranktip [Online]. Available: <http://www.cranktip.com/how-it-works/> (URL).
- [5] Welcome to Kneesavers. (N.D.). Kneesavers [Online]. Available: <http://www.kneesaver.net> (URL).
- [6] S. Tupi, W. Lynk, M. Toney, “A Pivoting Crank Arm for Riders with Limited Left Knee Flexion,” in *Resna Annual Conference*, Durham, NC, 2009. [Online]. Available: <https://www.resna.org/sites/default/files/legacy/conference/proceedings/2009/SDC2009/Tupi.html> (URL).
- [7] Q-Rings. (N.D.). Rotor Bike Components. [Online]. Available: http://www.rotorbikeusa.com/products/qrings_standard.html (URL).
- [8] Shimano. (N.D.) "FC-6800", *Bike.shimano.com*. [Online]. Available: <http://bike.shimano.com/content/sac-bike/en/home/components11/road/ultegra1/fc-6800.html> (URL).
- [9] FC-M9020-2. (N.D.). *Bike.shimano.com*. [Online]. Available: <http://bike.shimano.com/content/sac-bike/en/home/components11/mountain/xtr-m9000/fc-m9020-2.html> (URL).
- [10] Super Record Crankset. (N.D.). *Campagnolo.com*. [Online]. Available: http://www.campagnolo.com/UK/en/Components/super_record_crankset (URL).
- [11] XX1 Eagle Chain. (N.D.). *Sram.com*. [Online]. Available: <https://www.sram.com/sram/mountain/products/xx1-eagle-chain> (URL).
- [12] CN-9000. (N.D.). *Bike.shimano.com*. [Online]. Available: <http://bike.shimano.com/content/sac-bike/en/home/components11/road/dura-ace-di21/cn-9000.html> (URL).
- [13] Muc-Off Nano Chain. (N.D.). *Muc-Off UK*. [Online]. Available: <https://muc-off.com/products/nano-chain> (URL).
- [14] XG-1299 Eagle Cassette. (N.D.). *Sram.com*. [Online]. Available: <https://www.sram.com/sram/mountain/products/xg-1299-eagle-cassette> (URL).
- [15] Super Record Sprocket. (N.D.). *Campagnolo.com*. [Online]. Available: http://www.campagnolo.com/US/en/Components/super_record_sprockets (URL).
- [16] CS-6800. (N.D.). *Bike.shimano.com*. [Online]. Available: <http://bike.shimano.com/content/sac-bike/en/home/road/drivetrain/cassettes0/cs-6800.html> (URL).