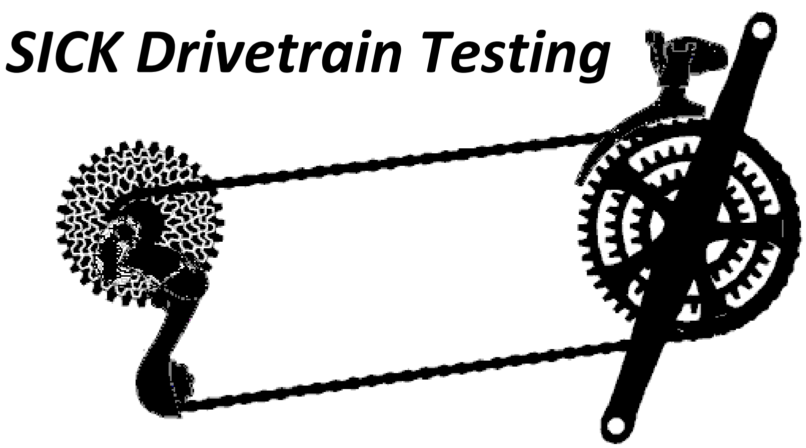
Loaded Shift Tester



June 2013

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Abstract

This report details the design, manufacturing, and testing of a loaded shift tester for the SRAM Bicycle Corporation. The machine is used to perform developmental and qualification tests on various bicycle drivetrain components. Using SolidWorks, the design team created a solid model of the machine on the computer, then ordered and manufactured the parts required to build it. The machine was tested to ensure that all the parts worked together, and was finally delivered to SRAM when it was deemed ready.

Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

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Chapter 1 – Introduction

Sponsor Background

SRAM, LLC is a bicycle components manufacturer based out of Chicago, Illinois. Established in 1987 as a drivetrain component manufacturer, their first major breakthrough in the bicycle industry was the patent and market introduction of the grip shift system. This system used a twisting, indexed shifter on the handlebars that was revolutionary for the time. After dramatic growth during the early 1990s, SRAM began acquiring other bicycle component manufacturers. Today, the companies under SRAM's umbrella include RockShox suspension, Truvativ drivetrain and cockpit components, Avid brakes, Zipp wheels and cockpit components, and QUARQ power meters. Additionally, SRAM supports the worldwide bicycle community through their nonprofit organization World Bicycle Relief. This group distributes bicycles to communities in developing countries on a very large scale. The programs focus primarily on education, economic development, and health care. The bicycles are designed specifically for where and what they'll be used for, and mechanics are trained to maintain the bicycles. SRAM is an enthusiastic supporter of all things bicycle-related and are constantly pushing the limits of engineering and innovation in their designs and programs.

Formal Problem Definition

SRAM is in need of an automatic loaded front derailleur test machine at their San Luis Obispo, California design center. Currently, they have several hand-operated test machines that test for characteristics like derailment and maximum strength in drivetrain components, but they would like something to perform development and qualification tests on. This will come in the form of an automated test stand that will be able to automatically drive the system while collecting data as the test operator shifts through the gears (there is also the possibility of adding automatic shifting capabilities in the future). These development and qualification tests will be used to look at the performance characteristics of front chain rings and chains, and their interaction with one another and the front derailleur. The main stakeholders in this project are SRAM, Cal Poly, and the SICK Drivetrain Testing team. The main goal of this project will be to have a fully-functioning machine that has been completely documented with a comprehensive instruction manual. The machine will include an interchangeable bicycle drivetrain apparatus, motors to drive the drivetrain automatically, a device to provide resistance to the drivetrain, and a computer program to monitor the tests and record data. SRAM will be provided with a full set of solid models and part drawings so that the machine can easily be reproduced or repaired, as well as maintained at a proper performance to preserve the integrity of the tests being completed. A full operations manual will be included as well to facilitate the use of the machine in conjunction with its computer interface and programming, allowing the test technician to successfully run tests in addition to being able to troubleshoot any problems.

Objectives and Specifications

The overall goal of this project is to build a loaded shift test machine to run development and qualification tests on front chain rings, front derailleurs, and chain designs for front shifting. This machine will successfully shift the chain and be able to record the position of the chain ring and front derailleur, as well as the torque input. This machine must be fully adjustable to

account for any type of crank or bottom bracket system, any front derailleur system, and various chain stay lengths. The mount for the front derailleur must also be adjustable for angle and misalignment. The machine should be able to load a profile or constant torque. The shifting will be done manually by test technicians, though the machine must be designed to possibly incorporate automatic shifting in the future. Technicians should be able to view testing during operations. Fully detailed drawings of the test machine are required so that machine could be reproduced. An operations manual is also required detailing operations, maintenance, and safety procedures for the test machine.

The specifications for the test machine have very specific and precise values that must be met in order for the machine to perform as intended. Table 1 shows these values and tolerances for the above-mentioned adjustability and compatibility requirements.

The precision of the adjustability requirements are very important, as bicycle geometries are very sensitive to small changes in angle and tube length. The objective of hitting these adjustability requirements with the desired range of values and tolerances will be both difficult and what makes this machine useful as a qualification and development test machine.

Table 1. Specifications and requirements for SRAM test machine.

Specification #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Force input	250 lb	max	M	A, T, S
2	Chainstay length	300-500 mm	±1.0 mm	H	A, T
3	Chain line adjustment	±10 mm	±0.1 mm	H	A, T
5	Chainstay angle	61^{o}-69^{o}	±1.0^{o}	H	A, T
6	Cassette capacity	9-42 teeth	-	H	A, T
7	Chainring capacity	22-55 teeth	-	H	A, T
8	Resistance at rear hub	250 lb	max	M	A, T, S
9	Bottom bracket compatibility	BSA and BB30	-	H	A, T
10	Seat tube diameter	31.8 and 34.9 mm	absolute	L	T

The minimum requirements of this test machine are quite simple. For a road-specific drivetrain, the test machine needs to be able to manually upshift a standard 130 mm BCD (bolt circle diameter) 53/39 tooth crankset with any bottom bracket. For a mountain-specific drivetrain, the machine needs to be able to manually downshift either a double or triple crankset with any bottom bracket style. Both styles of drivetrain need to be driven with a loaded profile and constant torque with an appropriate resistance at the rear hub.

Chapter 2 – Background

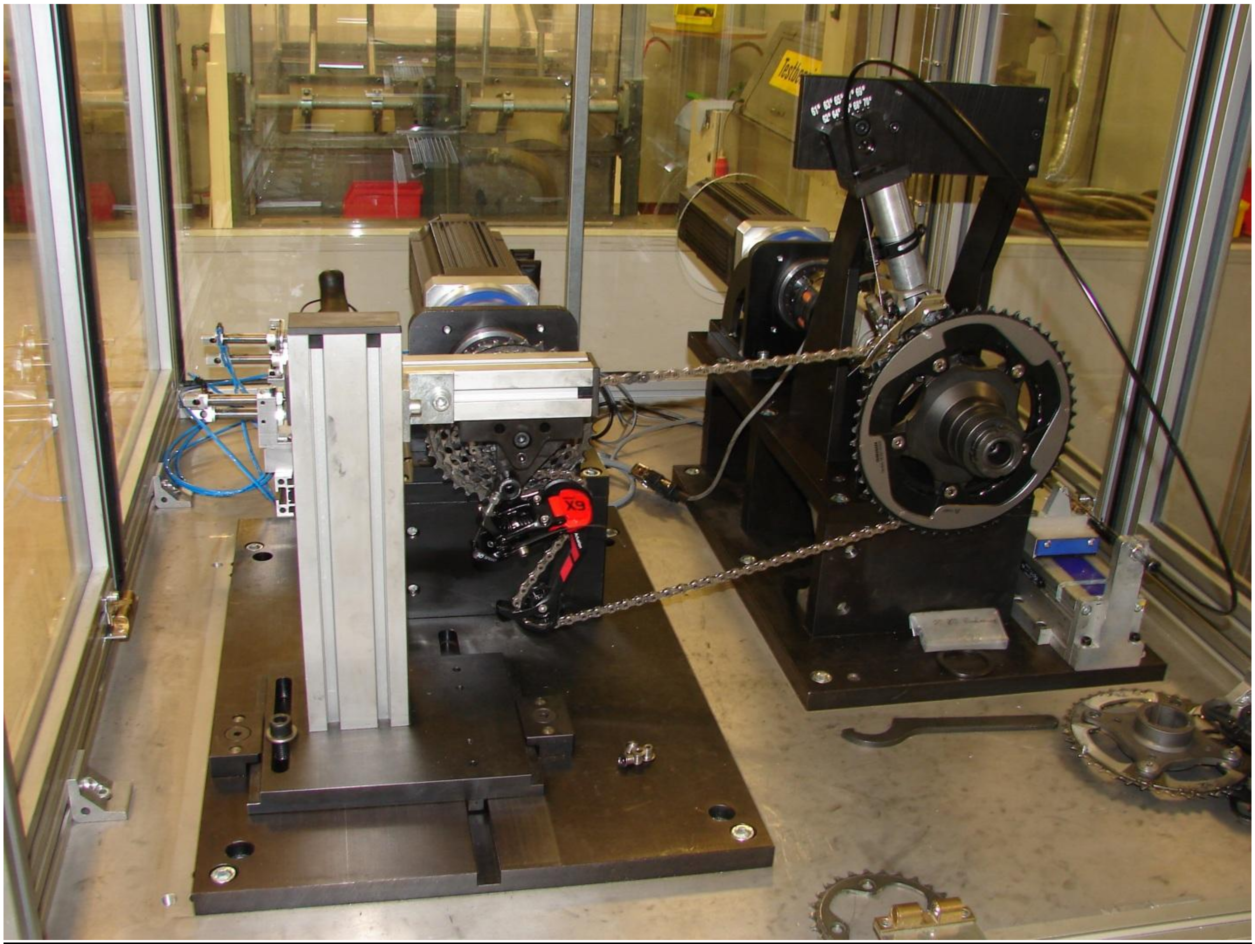

Figure 1. Current test machine in Germany office.

SRAM already has a number of shift test machines in use, but none that encompass all the features that this new one will. In their Germany office, the company has an endurance shift test machine that tests the fatigue life of front chain rings and chains as shown in Figure 1. It incorporates all the features that the new machine will, though with some modifications. The current machine is a bicycle drivetrain mounted to a rigid aluminum support structure. The front end of the drivetrain is driven by a motor through a shaft to a machined spider, which the chain ring is bolted to. The front derailleur is attached to an adjustable angle tube to account for varying seat tube angles of bicycles. This whole assembly is rigidly attached to the base. The rear end of the drivetrain is attached to a mount on slides in two different directions. The rear derailleur can slide back and forth in a track to adjust chain stay length. The entire rear assembly is in a slide and held down by clamps and can be adjusted to account for different chain lines and misalignment. The cassette is located on a modified hub attached to an electric motor which provides variable resistance to the drive motor. The front and rear derailleur cables are run to a pair of road shifters, where each has two pneumatic pistons positioned to shift the drivetrain. The entire test machine is on a table and enclosed by an impact-resistant, clear

plastic. This provides a safe operating environment should anything go wrong with the machine as well as allowing for the real-time viewing of the test in progress. There is also a computer and monitor attached to the side of the machine to control and monitor the tests.

SRAM has encountered a few problems with this machine in the course of testing. For one, the machine is not very rigid. Since bicycle frame geometries are sensitive to misalignments as low as ±0.1 mm, rigidity is key to developing a useful test machine. The machine allowed for significant movement in the components, and the test runs are not very useful for accurately measuring shift capabilities. Additionally, the German machine is unable to be loaded from a profile, meaning that the driving forces cannot accurately mimic a rider on a bicycle. These are two design considerations that are of the utmost importance for the new shift test machine. Additionally, SRAM has found that this machine is simply too powerful to run development and qualification tests on chains. When the machine is run slowly, the torque cannot be brought down low enough and components break or become mangled before any useful data can be gleaned from the test. This will be important in the new test machine, as it will be important to closely relate the loads to the possible loads that a rider would put on the components.

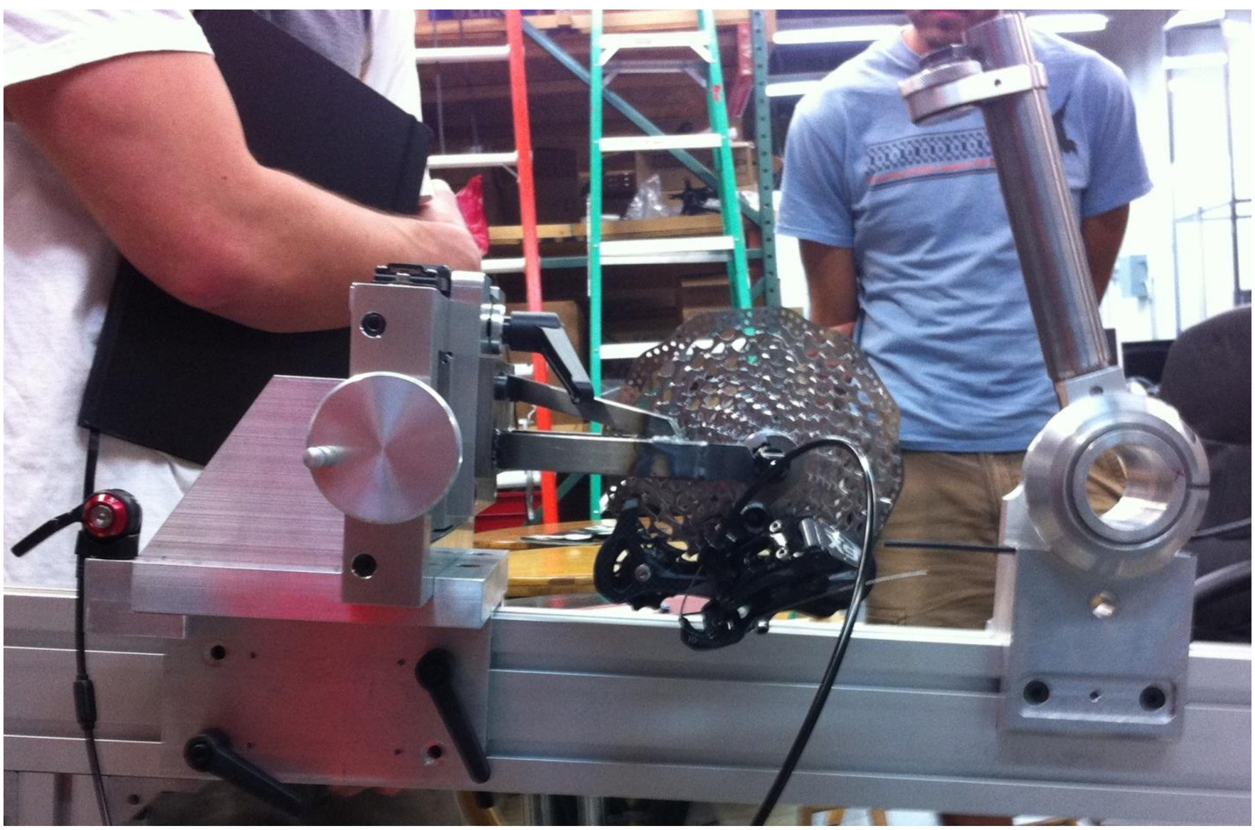

Figure 2. Hand-operated drivetrain test stand.

Recently, SRAM received a new hand-operated test machine to perform much slower versions of the tests the new machine will be used for and without any data acquisition equipment. The basic setup of this machine is shown in Figure 2. This machine is very similar in construction and design to what the new machine will be, just stripped down and much simpler. This machine allows chain ring design engineers to perform quick checks on chain ring prototypes and gather data by just watching the test. The new machine will encompass all the characteristics of this hand-operated test stand but with many, many additional features.

Materials Research

Linear Actuators

There are three major types of linear actuators; hydraulic actuators, pneumatic actuators, and electro-mechanical actuators. There are advantages and disadvantages to each of the three but for applications for the drivetrain test machine electro-mechanical actuators are the best choice. The power sources for both pneumatic and hydraulic actuators are large, loud, and require regular maintenance. For this machine, space limitations do not allow for a hydraulic pump system or an air compressor. The power source for electro-mechanical linear actuators is simply electric power. Within the realm of electro-mechanical linear actuators there are three major types: ball screw, Acme screw, and roller screw. Ball screws work in a similar way to ball bearings in that spherical bearings lie between two concentric cylinders. The difference with the actuator is that the bearings travel along a helical path around the inner cylinder. Acme screws have a considerable amount friction during operation and are prone to

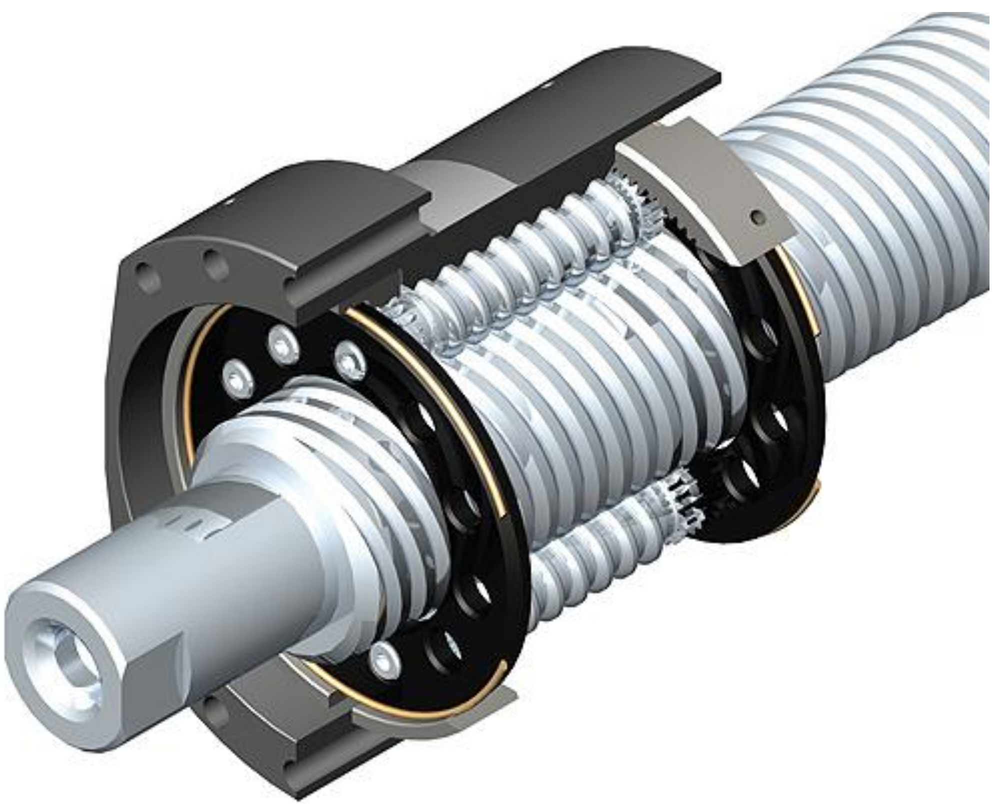

Figure 3. Cross-section of Exlar roller screw linear actuator.

wear and inefficiency. Roller screw actuators can achieve higher speeds than both acme screws and ball screws and they are much more efficient because they have many more contact points within the same space. Figure 3 shows a cross-section of a linear actuator of the roller screw type. The most appropriate type of linear actuator for the test machine is the roller screw type because they can achieve the high speed and low backlash required for the application. This type of linear actuator will allow the test machine to be driven at an appropriate speed while easily achieving the maximum loads needed. Unlike the motors in the German test machine that SRAM has that is too powerful, this configuration utilizing a linear actuator will very closely imitate the speed and power provided by a rider.

Aluminum Profiles and Housing Options

Aluminum extrusions are available for purchase through various vendors who sell complete systems or any subset of a system. For the test machine, aluminum extrusions will be the simplest way to assemble the frame and housing. These systems are available with many features, such as hydraulically-actuated doors, locking mechanisms, and other safety options. The aluminum profiles are designed to easily mate to one another and will provide a stiff and light frame to mount the test equipment to. These aluminum extrusions are designed to accept paneling as well, which would allow for the easy and safe implementation of viewing windows. Additionally, many different styles of doors are available with these aluminum extrusions, further decreasing the amount of machining needed. By purchasing a pre-manufactured system, the housing will be far easier to assemble and require much less design time by the design team. The only machining that will be required is cutting down stock lengths of extruded aluminum and finishing operations. The housing will be able to be assembled using hand tools.

Adjustment and Alignment Options

Due to the importance of the precision in adjustment and alignment for the test machine, finding components that are very stiff, rigid, and precise is a key design factor. Many components that fit the needs of this project are available through vendors for purchase. There are many options to buy slides and guides that are adjustable via lead screws with handles, such as standalone vertical milling machine tables and single-axis guides. Since two-axis adjustment is necessary for this test machine, a milling machine table will likely be used to achieve very precise and rigid 2-axis movement. These products are able to provide adjustment down to 0.001 inches, which is adequate for this purpose.

This background research will provide a platform for the design team to begin purchasing materials and designing the system around pre-manufactured products.

Chapter 3 – Design Development

The first step in the design process is to analyze the current machine to figure out its capabilities and limitations. This will provide a good starting point that will be used as a basis for the new loaded shift test machine. After getting a better idea of what this machine should look like, the team will brainstorm new design concepts for the project. All of these conceptual ideas will go through a decision matrix to help select the optimal design. The machine design

will then go through a conceptual design review at the sponsor's site. With approval of the conceptual design, the next stage will be solid modeling and prototyping. The controlling program will be written while prototypes of test machines are being built. A LabView program will be written to control the power input for the drive motors and to collect the data from the various measurement sensors in the system. The design process will be completely documented with CAD drawings to allow for future manufacturing. The last step is to write a manual with operating procedures, machine maintenance, and safety instructions. Final production tests will be performed insuring that the machine is safe and ready for testing in the SRAM's California design center.

Since the basic overall layout of the test machine had been previously developed, it was simpler for the design team to break the system into subsystems. These subsystems were designed separately, with final system integration kept in mind during the whole design process. The test machine was broken down into the following subsystems: front drivetrain, rear drivetrain and resistance, shifters, and housing and control. Concepts were chosen based on feasibility of design, manufacturability, simplicity of design, ease of integration into the whole test system as well as the other test machines and components SRAM currently uses, and how well the concept accomplishes the required task.

Front Drivetrain Subsystem

The components in the front drivetrain will be the power input to the system, dynamometer, bottom bracket and seat tube assembly, and sensors to measure chain ring

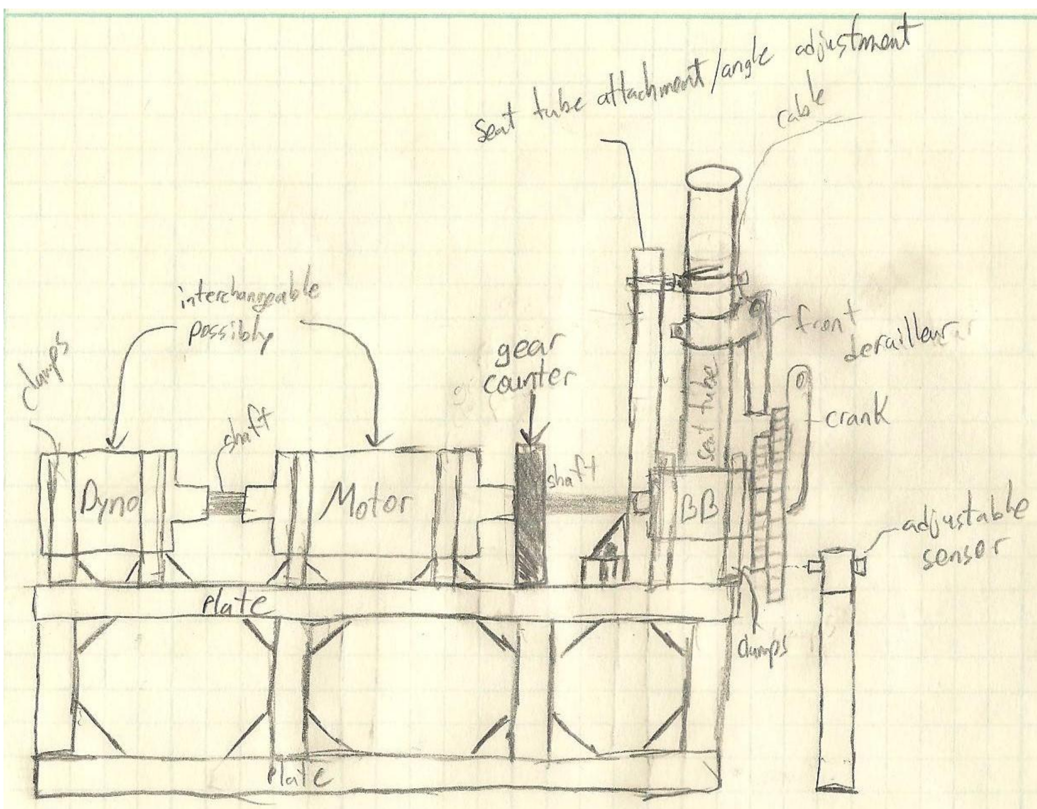

Figure 4. Front drivetrain layout including all components.

position. One option for the power input to the system is a rotary motor that drives a shaft that is directly connected to the spindle of the bottom bracket system. A layout of this possible design is shown in Figure 4. This type of input does not accurately represent how a human rider drives the cranks, but it should be good enough for the purposes of the testing. One issue with this method is that torque and speed are dependent on one another with a rotary motor. In order to get the required torque for the system, the motor will have to be running at a specific rotational speed that might not represent the speed at which a human rider would actually pedal. A series of gears would need to be used in order to achieve the appropriate torque and speed for the system.

The torque input must be measureable and controllable for the testing that will be done on this machine. The dynamometer will be positioned in-line with the motor in order to measure the torque and rpm for the system. The motor will be connected to the controller for the system so that a specific torque can be applied.

A shaft will run from the motor to the bottom bracket and seat tube assembly. The bottom bracket component will consist of a single outer shell and various inner shells to account for several different bottom bracket styles. This outer shell will then be secured in a C-clamp assembly that is then bolted down to a rigid base plate. A small component will be machined to connect the seat tube to the outer BB shell. A couple different sizes of this component will be made to account for the different size seat tubes available. The C-clamp can be loosened to allow the bottom bracket shell and seat tube assembly to be adjusted for seat tube angle.

Measuring the chain ring position when a shift occurs will be one of the more difficult tasks for this machine. One idea is to use an electronic sensor positioned either on the inside or outside of the chainrings. This sensor would be adjustable vertically in order to lineup with

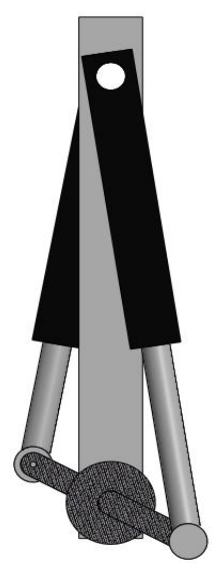

Figure 5. Possible layout for drive mechanism using two linear actuators.

different sizes of chainrings. Marks would need to be made on the chainrings in order for the

sensor to be calibrated. Once calibrated, the sensor should be able to determine when a shift occurs by when the sensor no longer can read each individual tooth. At this point, the chain has shifted and now covers the marks made on the chainring. A high speed camera will also be placed inside the machine housing and would be used to help capture these shifting moments.

All of these components will be attached to aluminum structures because rigidity and alignment are important factors when setting up this machine.

An alternative to using a single rotary motor is to use two linear actuators to drive the pedals, similar to the way a bicycle is actually pedaled. This design is shown in Figure 5. Achieving torque magnitudes similar to those produced by a person riding a bicycle would require a very large electric motor and require a gear reduction mechanism to make the rotational speed of the crank lie within the normal operating range seen for most riders. Rather than driving the crank with a rotational input, it could be driven using linear actuators. Two linear actuators would be needed for this application, one for each side of the crank.

This idea simulates the application of forces much more closely than a rotational motor; each linear actuator acts like a person's leg pushing down on the pedal. The two actuators will be programmed such that when one starts extending the other retracts the same distance and when the crank arms reach a vertical orientation the two actuators switch directions to continue the rotation of the cranks. The pivot point of the two linear actuators needs to be located above the bottom bracket to match the deflection of the crank arms and the corresponding effect on front shifting the same way that a rider causes flexing of the cranks during hard pedaling.

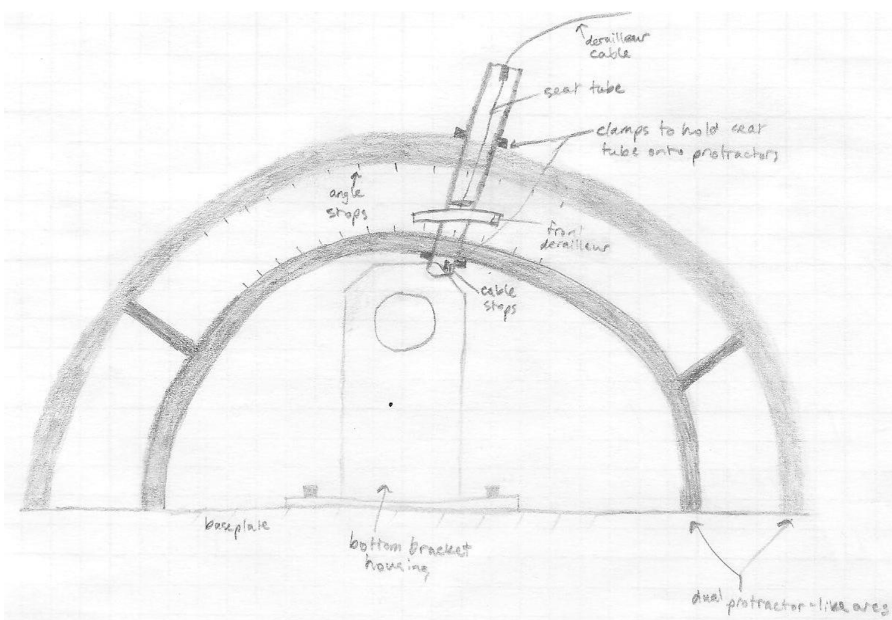

Figure 6. Possible layout for seat tube angle adjustment using double-arc design.

The main problem with this design is that the linear actuators could begin to work against one another if the rotation is not kept up. When one crank is at the bottom of the rotation and the other is at the top, the linear actuators could get stuck and begin working

against each other. This could cause failure of the motors and possibly damage to the system. Additionally, it would be difficult to achieve the proper rotational speed for this design.

One design consideration that took some serious thought was how the adjustment of the seat tube angle would be accomplished. Several ideas were discussed, all involving a rotating tube on some kind of rigid support structure over the bottom bracket housing. The first idea considered is shown in Figure 6. This design employs a double-arc that would allow the seat tube to slide along and adjust the angle as it moved. If this design were to be implemented in the final test machine, it is likely that the double-arc would be replaced by a robust single arc in order to maintain stiffness of the structure and eliminate the possibility of misalignment between the two arcs or any binding that could occur.

Another possible design to accomplish this task is already employed by SRAM in some of their other test machines. In this layout, the seat tube angle is adjusted by rotating an interchangeable seat tube around the bottom bracket assembly. This design is much simpler than the design proposed in Figure 5, and would simplify things for the design team as the component is already manufactured and could easily be replicated for use in the new test machine. Additionally, the existing component already has provisions to allow for the variation of bottom bracket styles. Figure 7 below shows the bottom bracket shell and seat tube assembly, and Figure 8 shows the interchangeable bottom bracket assemblies that fit into the bottom bracket shell.

Figure 7. Bottom bracket shell and seat tube assembly allowing for angle adjustment.

Figure 8. Various bottom bracket assemblies that fit into bottom bracket shell and seat tube assembly.

The design shown in Figures 7 and 8 will likely be the chosen for use in the new test machine. The design and manufacturing are already done, which simplifies things greatly for the design team. Additionally, this design is already implemented in several of SRAM's existing test machine, so utilizing it in this new test machine will allow for more interchangeable parts between machines and minimize the number of specialty parts required to perform testing.

Rear Drivetrain and Resistance Subsystem

The components in this subsystem are the rear derailleur, cassette, absorption dynamometer, and the fixtures to hold everything in place. This layout is shown in Figure 9 below. The rear drivetrain fixtures will be the location in which all distance adjustments will be made: these include chainstay length, relative bottom bracket drop, and lateral frame misalignment. The simplest approach to adjustability is to bolt all the components to slotted aluminum extrusions. This would be inexpensive and would provide a wide range of positions. There are two major issues with this idea; the first problem is the time and effort required to make an adjustment considering every bolt holding a particular component down would need to be loosened and then tightened to the appropriate torque specification. The second and more crucial issue is the prevalence of misalignment in setting up components in slotted channels. The tolerances between the bolts and the channels are loose and would be difficult to set up such that components are aligned properly with one another. An alternative approach to adjustability is to mount all the components to a plate that sits atop a three axis adjustable

platform much like a vertical mill table. Each of the three required adjustments would be made in an arbitrary x, y, and z axis and would correspond to the chainstay, lateral misalignment, and bottom bracket drop adjustments. The adjustments will be made with hand cranks for each of the three directions.

The absorption dynamometer is providing rotational resistance to simulate a load on the drivetrain components. One option for fixing the cassette sprockets to the dynamometer is to machine a shaft that mimics the mating surface of a cassette free hub body and mount the cassette directly to the dynamometer. This requires complicated machining and also presents a difficulty in mounting and aligning the rear derailleur with respect to the cassette.

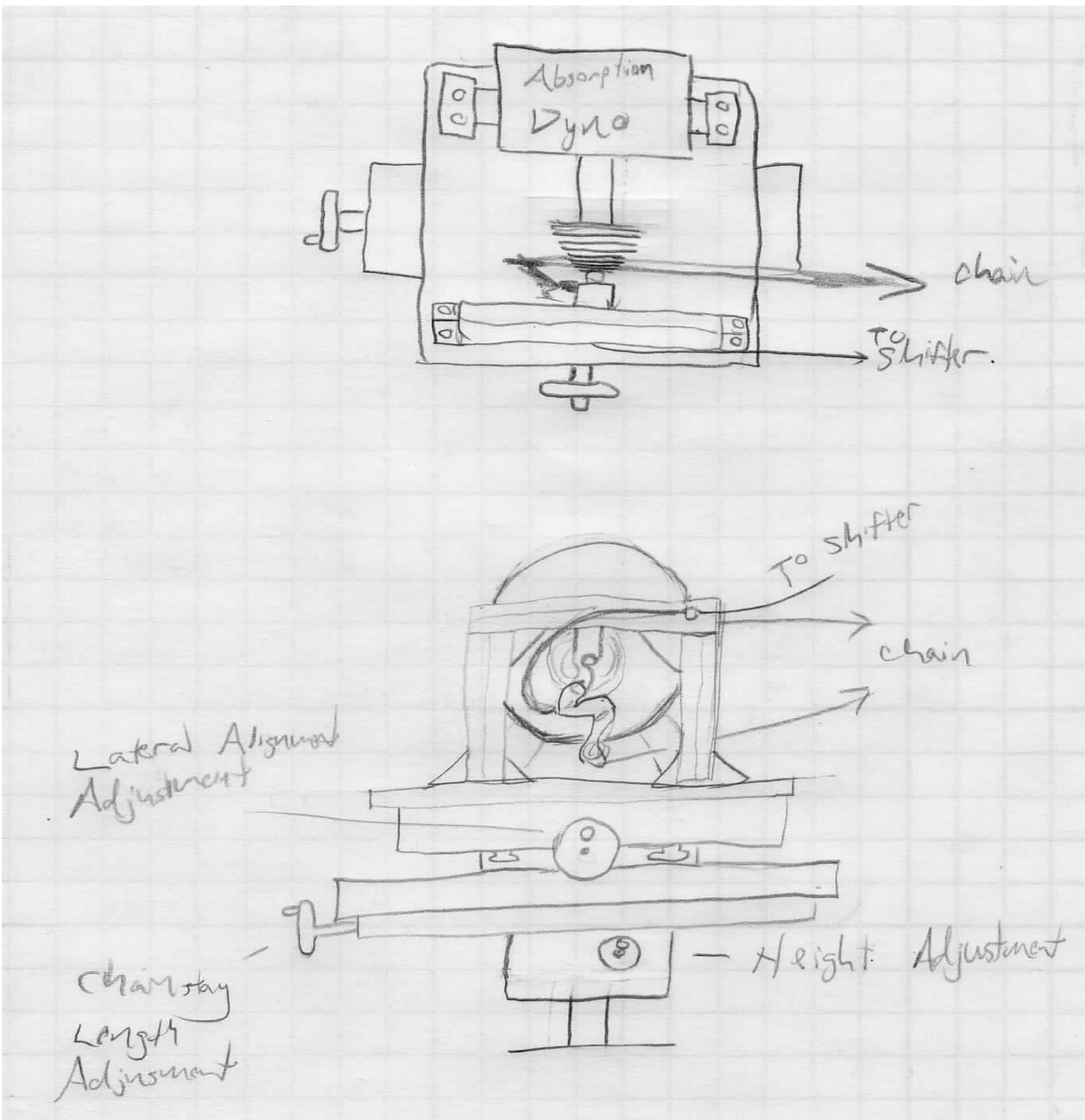

Figure 9. Possible design layout for rear drivetrain subsystem.

A second

option is to install the cassette on a typical disc brake mountain bike rear hub and mount the hub on the machine using dropouts similar to those found on a bike frame. A pulley wheel will be bolted to the disc brake mounting holes on the hub and will be connected to the dynamometer with a belt drive. This option allows for much more consistent positioning of the derailleur and cassette and will be easier to manufacture.

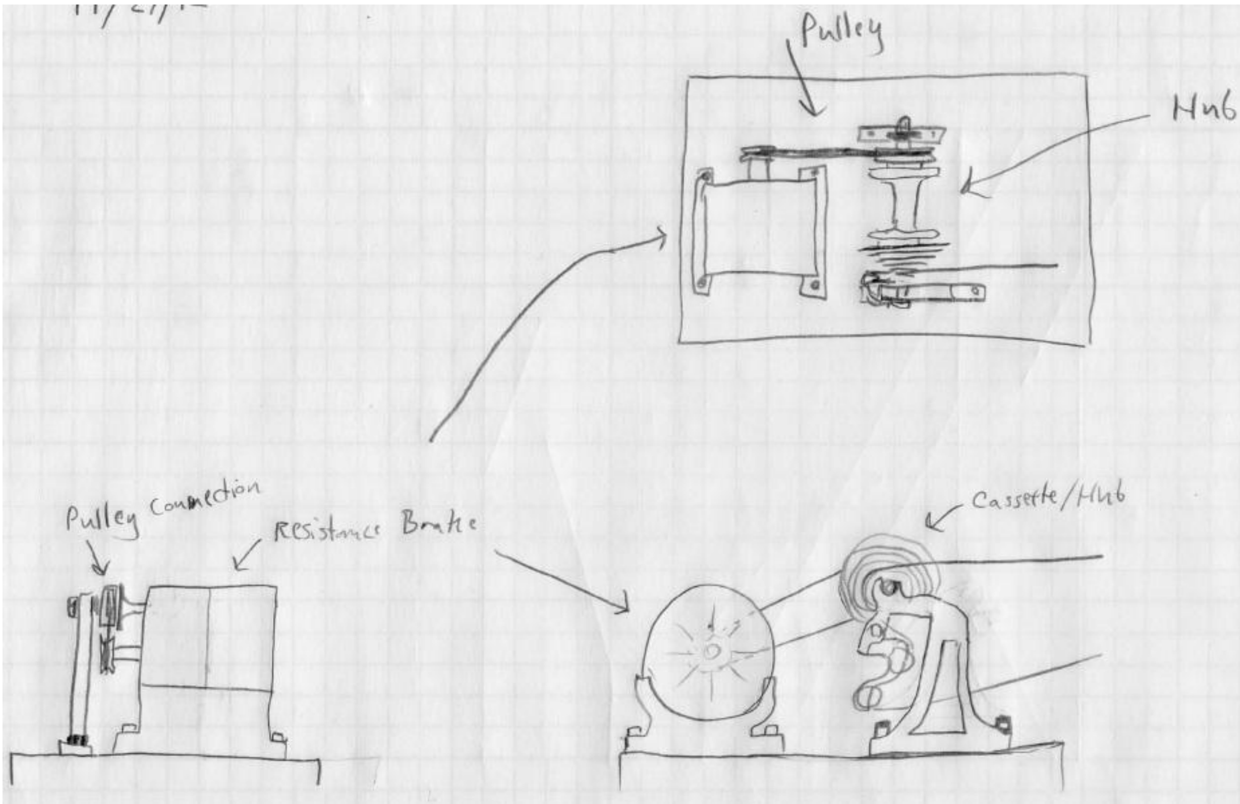

Figure 10. Resistance at the rear drivetrain.

Figure 10 shows the possible design of a resistance layout for the rear drivetrain. Since the load at the pedals will be based on the resistance at the rear axle, it is important that the resistance is easily adjustable so calibration can be performed.

Shifter Subassembly

The components of this subsystem include the shifters, mounting system for the shifters, actuators to automatically shift, and the mounting system for the actuators. Several types of shifters will be mounted to a section of handlebar in order to account for the different gear combinations available in products to be tested. Additionally, the subsystem will be able to accommodate either road or mountain style shifters of any brand for testing of any shifter style on the market. Each shifter will have a dedicated cable and housing already attached to make it easy to switch between shifter styles and front and rear derailleurs. The handlebar section will be attached to the test surface via a direct-mount style stem and bolted directly to the test surface. This layout is detailed in Figure 11.

In order to engage the shifters, actuators will be used. Pneumatic pistons and linear actuators have been considered, and linear actuators have been determined to be the better choice for several reasons. First, the rest of the system will be run with electricity providing the energy and therefore it will be easier to continue using electric power for this subsystem instead of introducing air power for just one individual purpose. Second, the action of a linear actuator can be controlled more easily and accurately with a computer than a pneumatic piston. Finally, linear actuators can have integrated load cells that will transmit how much force is being applied to the shifters when actuated. These linear actuators will be outfitted with small bumpers at the end of the reciprocating arm to provide an appropriate surface to meet with the shift levers. The

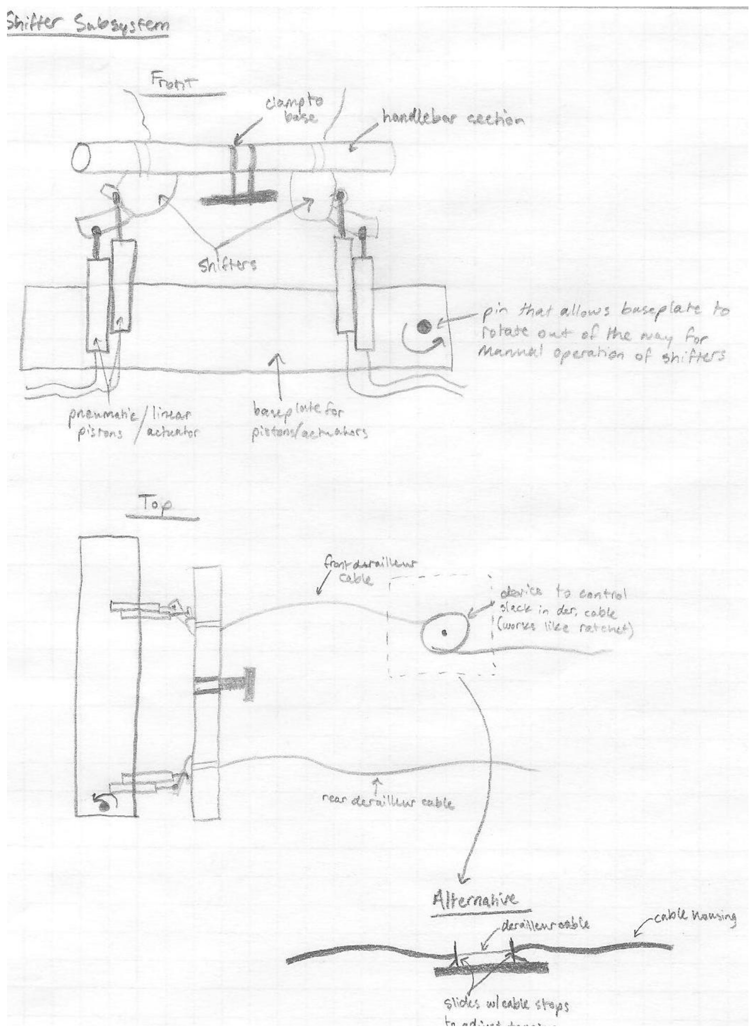

Figure 11. Shifter subsystem detailing component placement and movement.

linear actuators will be mounted to a plate that will be able to slide or pivot out of the way to allow for manual operation of the shifters.

This entire subsystem will be controlled by the computer and will be programmable for automatic shifting during a test run. The force and amount of time to engage the shift at the shift lever will be transmitted to and recorded by the computer. This design should allow for very reliable shifting during testing and allow the test operator to manually shift the system if the test protocol calls for such an action.

Housing and Controller Subsystem

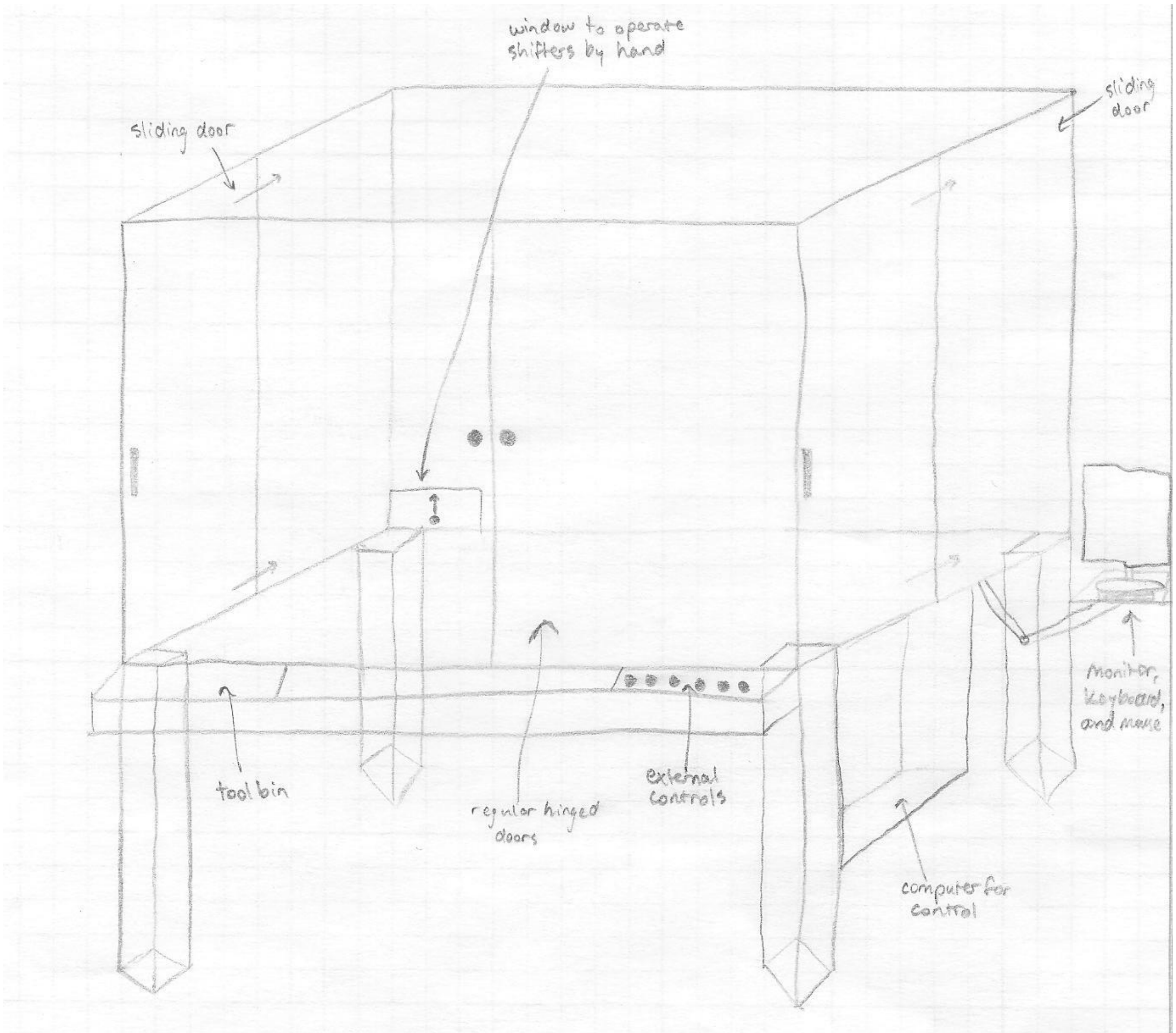

Figure 12. Housing and controller subsystem detailed layout.

The components in this subsystem include the test surface, the housing for the entire apparatus, and the computer used to control the test system. The basic layout is shown above in Figure 12. The test surface will be where the front and rear drivetrain subsystems will be mounted, along with the shifter subsystem and all the support pieces that will hold the entire system together. This surface will be supported by a frame made of pre-manufactured aluminum extrusions that will hold the test surface as well as the access doors and windows to allow for live viewing of the test.

The upper portion of the housing will be filled in by polycarbonate panels to allow the test operator to view the test in progress as well as protect the operator in case of component failure. Polycarbonate has been selected as the optimal material for this purpose because of its clarity and impact resistance. The front side will have two Lexan door panels utilizing traditional swing-open door hinges to allow for the adjustment of most major components. These doors

will have a device to lock them in the shut position when the components are not being adjusted. On the two side panels, Lexan panels will be used as sliding doors to allow access to different parts of the system that what is easily accessible from the front. As with the front doors, these side panel sliding doors will have devices in place to lock them in the closed position when not being used. Additionally, one of the panels (most likely the rear panel) will have a small vertical sliding window to allow for the manual operation of the shifter subsystem. This small window will be large enough for the manipulation of the shifts but not so large as to endanger the operator or compromise the safety of the entire system.

The computer and monitor will be mounted on the side of the system under the test surface. The computer will be mounted directly underneath the test surface, out of the way from the operator but still easily accessible in case maintenance is required. The monitor, mouse, and keyboard will be mounted on an articulating arm extending from the side of the housing for easy access and manipulation during and between tests. This layout will be very similar to that of the German test machine, shown below in Figure 13.

Figure 13. Housing and controller of existing German test machine.

On the front of the support structure will be a tool bin as well as the manually-operated buttons for running, powering on and off, and emergency shut-off. The tool bin will have all the tools required to make adjustments to the test apparatus and replace interchangeable components between tests. This system will provide the required support and access for the test apparatus to be successful, as well as provide necessary safety precautions to protect the test operator and surrounding machinery in case of component failure.

Chapter 4 – Description of the Conceptual Design

For the conceptual design, several of the initial concepts are utilized and combined to form the best solution possible to the problem. After careful consideration, each subsystem's detailed design was completed and modeled in SolidWorks. This allowed for verification of all the subsystems fitting together in the allotted space, and that the appropriate clearance was allowed. Additionally, this allowed the team to come up with an accurate bill of materials to begin ordering parts and ensure that enough of each part was ordered (this is especially important for the housing and control subassembly). The following sections detail the conceptual design for each subsystem and show how they will all integrate together.

Front Drivetrain Subsystem

The front drive train assembly includes several complex components. The fixture for the cranks, bottom bracket, and seat tube will consist of several clamps along a single axis. Two of these clamps hold the interchangeable 60 mm diameter bottom bracket shell in place; a third clamp secures a collar to the bottom bracket shell and the seat tube mounts to that collar. The entire structure mounts to a 50 mm x 100 mm rectangular profile aluminum extrusion from MK North America Aluminum Framing Systems product line. On a parallel extrusion mounted behind the front cross member will be a low speed electric rotary motor. The motor selected for this application is a single-phase AC gear motor with a speed of 75 rpm at 10 in-lb of torque from McMaster-Carr. This motor will have a crank arm that connects to both the non-drive side crank arm of the test crankset and the ball joint end of the linear actuator. The actuator chosen for the main input to the machine is a Tolomatic RSA 32 with a reverse parallel mounted motor. This actuator can achieve velocities of approximately 24 in/s and will meet the maximum thrust target of 400 lbs. It will hang from a clevis mount on the ceiling of the machine with the clevis center to the right of the bottom bracket center when viewing the machine from the front.

The pairing of a rotary actuator and a linear actuator is intended to prevent the machine from binding up at top dead center or bottom dead center of the crankset rotation. The motor has a negligible amount of torque compared with the torque that the actuator will induce so it will not greatly influence force to the pedal. Its main purpose in the design is to maintain a consistent direction of rotary motion; it is analogous to the flywheel in an automotive internal combustion engine.

A chain derailment sensor will be located between the front and rear drivetrain assemblies connected to an automatic shut-off switch. The purpose of this sensor is to stop all driven components in the event of a chain derailment and prevent the machine from damaging itself or the components being tested. The seat tube apparatus is designed to be

interchangeable to incorporate the use of various front derailleur mounting methods such as direct mount, braze on, 31.8 mm clamp, and 34.9 mm clamp. The bottom bracket fixture and seat tube will allow for derailleur cable to be routed under the bottom bracket up to the derailleur

Figure 14. Solid model of front drivetrain subsystem.

or come in from the top through the adjustable cable stop on the seat tube.

Figure 14 above shows a solid model of the entire front drivetrain assembly. This includes the rotary motor, linear actuator, bottom bracket and seat tube assembly, front derailleur and cable routing solutions, and test crankset. This system will allow for easy integration into the rest of the test machine, as well as provide the needed drive characteristics for meaningful tests to be performed. It will also still be very rigid and allow for exact alignment, to ensure that all adjustments to geometrical values are made from the rear drivetrain and resistance assembly.

Rear Drivetrain and Resistance Subsystem

The rear drive train and resistance assembly is the component of the system in which all position adjustments of the rear hub relative to the crank position are made. All of the parts of this subsystem will be mounted on a mill table with 330 mm of travel in one direction and 130 mm of travel in the perpendicular direction within the horizontal plane. The dials on the mill table are indexed to 0.001" and one rotation of the wheel moves the table 1/16" which is within the target adjustment increment.

The parts include a rear derailleur, and mountain bike disc rear hub with 135mm dropout spacing, a Tolomatic mechanical brake caliper ME220 with an 8 inch rotor, and a dropout structure with mounting fixtures for the hub, the derailleur, and the brake caliper. The brake force will be modulated with a turnbuckle fixed to the brake lever cam with a jam mount and fixed to a bracket on the dropout structure with an eye mount. The brake manufacturer provides relations for determining braking torque based on lever force; the machine can be modified to

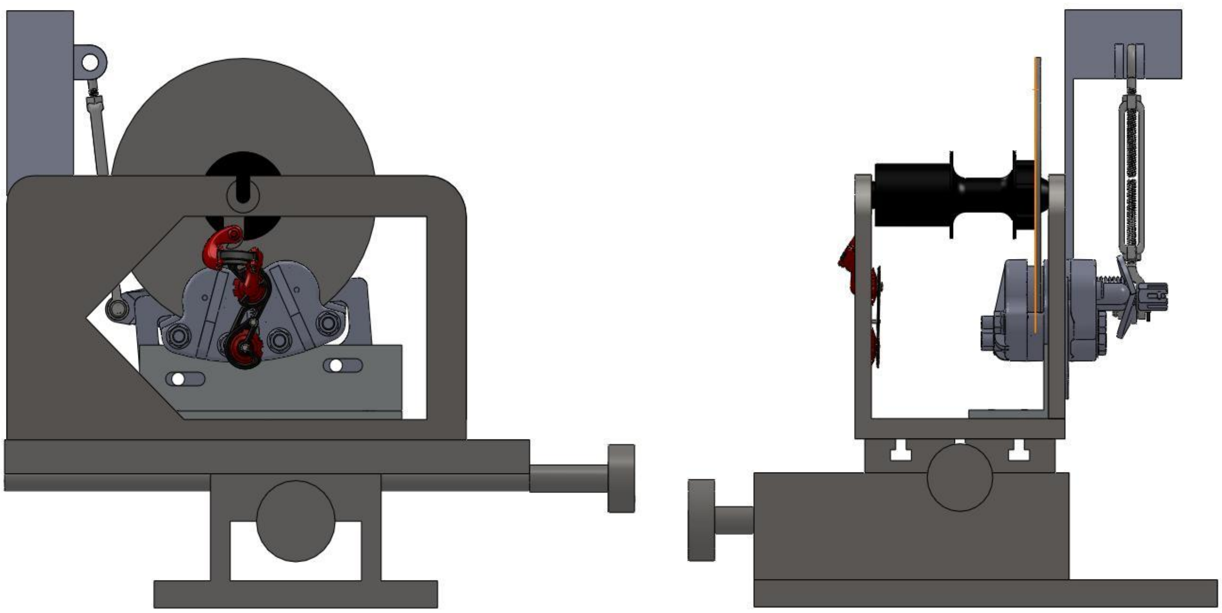

Figure 15. Solid model of rear drivetrain and resistance subsystem.

accept a force transducer or strain gauge to measure lever force and ultimately braking torque should the machine operator need to know that data.

Figure 15 above shows several views of a solid model of the rear drivetrain and resistance assembly. Large hardware and robust parts are used in all parts of the components, ensuring maximum rigidity. This will guarantee that the geometric tolerances can be achieved and the fine adjustments necessary will be possible.

Shifter Subsystem

The shifter subsystem will contain an aluminum extrusion as the base, a direct mount stem, a machined bracket to mount the stem, and a cut-off mountain bike handlebar to mount various shifters. The aluminum extrusion will have a 60x120 mm profile, which will allow the stem to be bolted down securely with two bolts on separate T-slots. This will provide enough rigidity to the design, as well as allow the mount to easily slide on and off to interchange separate mounts with different shifters, if necessary. A direct mount stem will be mounted to the aluminum extrusion with a custom machined bracket. A direct mount stem is a better option than a normal stem because it can easily be mounted to a plate with four screws/bolts. A normal stem needs to be clamped to a cylindrical metal piece, which would then need to be attached to the aluminum extrusion. This would require welding this cylindrical piece to a plate, which is one extra step than the direct mount option. The direct mount is also more compact providing more rigidity to the design. A mountain bike handlebar will be cut to a desired length and attached with the direct mount. Mountain bike handlebars are long and straight, allowing easy mounting of various styles of shifters to the machine.

Initially, this entire assembly was going to be inside the machine container with pneumatic or electric actuators to automate the shifts. After researching several actuators and

Figure 16. Solid model of shifter subsystem.

speaking with the engineers at SRAM, it was decided that automated shifting was unnecessary for this stage of the test machine. There were no electric actuators that were both the right size and able to provide the right speed for shifting. There were some pneumatic products that would work, but this would add another element and far more complexity to the design. The main scope of the project is to have an automated drivetrain with varying torque, and to observe the chain ring and chain when a shift occurs. This shift will be far more consistent and reliable with physical input from the operator of the machine. Since the operator will be the one engaging the shift, the assembly will be placed outside the container for ease of access. This way, the machine can be running safely with the doors closed and the operator can engage the shifters without having to put his or her hands close to moving components.

The shifter subsystem is shown above in Figure 16. This does not include the actual shifters, as the time to model them would not be worth it. Mounting this assembly to the outside of the machine will allow for very simple cable routing through the underside of the machine, as well as allow the test operator to choose the time and gear position to shift. The test operator will also be able to prescribe the force on the shift lever and the time to shift qualitatively. Additionally, the system has been designed to easily accept actuators for automatic shifting in the future.

Housing and Controller Subsystem

The housing will be made of rigid aluminum extrusions and assembly pieces sourced from MK North America's Aluminum Framing Systems product line. An emphasis was put on extreme overdesign of the frame, as machine weight is not a concern for this project. To ensure stiffness and rigidity throughout the frame, each joint has been connected with the largest and strongest hardware available and with the most connections possible. This, combined with high-tolerance machining, should yield an incredibly stiff housing for the test machine to be mounted on. A solid model of the housing assembly is shown below in Figure 17.

The housing has clear, impact-resistant polycarbonate panels around the sides to both provide protection for the test operator in the case of part failure and to allow viewing of the test in progress. The front has traditional doors that open outwards, that will allow for the operator to access all parts of the machine to make any adjustments necessary. A locking latch will be used between the doors to ensure that they do not accidentally open during a test or at any time the operator does not intend to open the doors.

The middle section of the housing is where the test machine will be mounted. This section is built up with larger extruded beams than the rest of the housing to ensure greater stiffness and make sure the system can handle the heavy static and dynamic loads. The narrow beam is from a different series than the rest of the housing to allow better clearance for the front drivetrain. This will ensure that the cranks do not come into contact with the housing during the test, which would cause failure. The front drivetrain and rear drivetrain and resistance subsystems will be mounted to this narrower beam. The rotary motor for the front drivetrain assembly will be mounted to the larger cross-beam, which will also provide additional support for the x-y table in the rear drivetrain and resistance assembly.

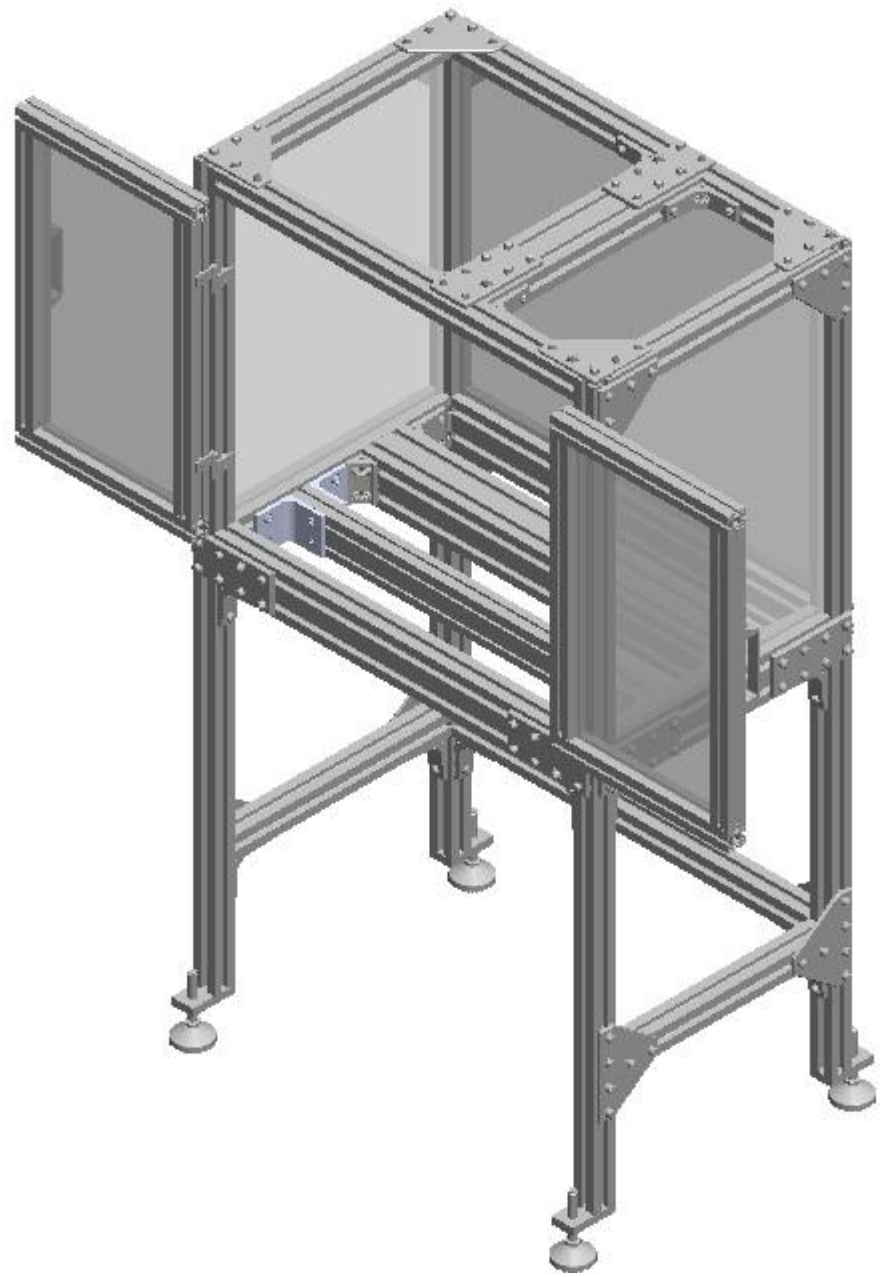

Figure 17. Solid model of housing subsystem.

The data acquisition system and all of the sensors used will be mounted to various parts of the housing assembly (not shown in the Figure 17). The T-slots in the aluminum extrusions will provide simple mounting solutions for all the sensors and should allow for easy positioning. The main DAQ system will be mounted on the underside of the main section, where it will be out of the way of the moving parts but still be close in proximity to limit data transfer errors due to wire length. This will be connected to an external computer, mounted to the side of the housing assembly where the test operator will be able to easily monitor the DAQ system during the test as well as issue instructions to the test machine. A tool organizer will also be mounted to the front of the housing assembly, where all the necessary tools to make any adjustments to the

test stand will be easily accessible. Some basic push button controls will also be included on the front of the housing, such as an emergency shut-off in case of machine failure.

Chapter 5 – Changes for the Final Design

After presenting the conceptual design to SRAM for approval, several changes were made to the design requirements so that the machine could be greatly simplified. The main change to affect the design was the drop of the maximum required load from 400 pounds at the pedal to 250 pounds. This allowed for the overall simplification of the drivetrain subsystems. Other changes were made to ease the use of the machine by the operator, as well as functional changes to produce a better test machine.

Front Drivetrain Subsystem

With the drop of the maximum load at the pedal to 250 pounds, the front drivetrain subsystem was made much less complicated. The linear actuator and rotary motor combination was replaced with a single drive motor connected through a 20:1 gear reducer to the cranks. The non-drive side crank arm is driven by an aluminum crank affixed to the output shaft of the gear reducer. Figure 18 below shows the solid model of the final system here. Other than the drive system change, the rest of the front drivetrain subsystem remains unchanged.

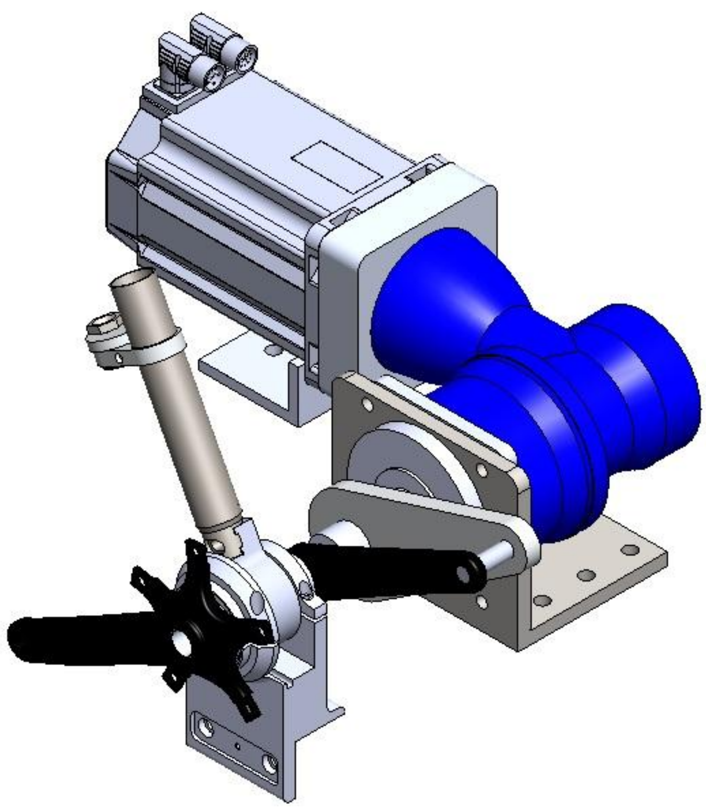

Figure 18. Final front drivetrain subsystem design including drive motor and gear reducer.

The motor used in the design is a Parker MPP1424 3-phase DC brushless/AC servo motor. In order to get the torque required for the machine, it runs on 240V 3-phase power. This

motor is run through a Wittenstein SPK Plus 20:1 gear reducer. This will allow the machine to reach the maximum torque required while hitting the speed target. A simple aluminum crank arm is used to drive the non-drive side crank, attached via a threaded steel spindle.

In order to check for chain derailment, a limit switch was originally going to be implemented. However, it was found to be very difficult to mount the limit switch in a position that would allow it to perform as intended for many different types of drivetrains. Therefore, derailment will be checked by the LabView program. The machine will be shut down if the resistance to the motor suddenly goes to zero.

The bottom bracket tower remains unchanged from the conceptual design, with all the required adjustments available. This component allows for easy interchanging of drivetrain parts of different standards and sizes.

Rear Drivetrain and Resistance Subsystem

The rear drivetrain and resistance subsystem underwent several small design changes. The original design used a two-axis x-y slide table, but it was decided that this arrangement would not be strong or stiff enough to withstand the significant forces acting on the rear hub assembly. This was changed to have a one-axis slide table that would account for the chain line adjustment, with the chainstay adjustment being taken care of by bolts with adjustable handles. Figure 19 below shows the new layout of the rear drivetrain and resistance subsystem.

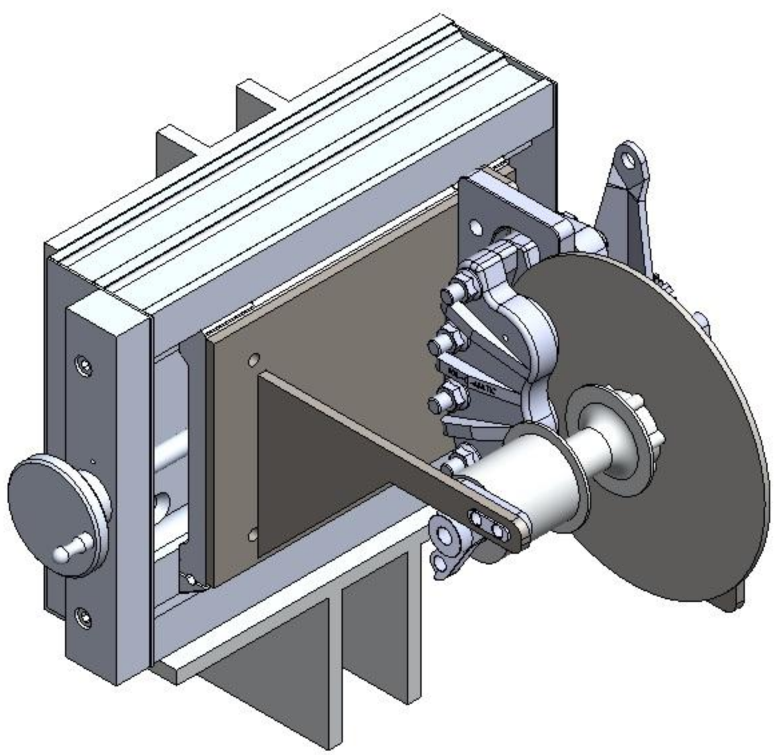

Figure 19. Rear drivetrain and resistance subsystem updated with design changes.

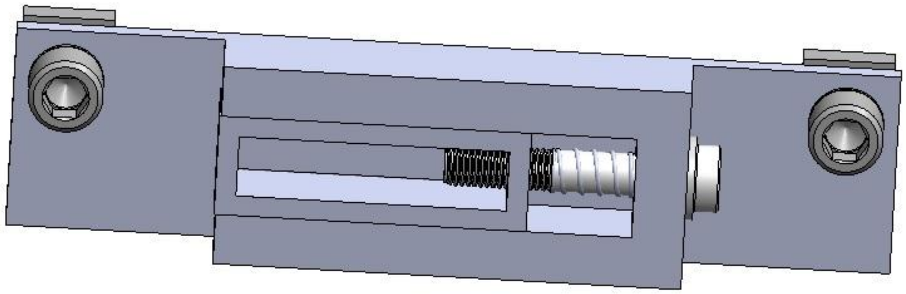

Figure 20. Brake actuator to apply load to drivetrain.

The brake is actuated by a sliding block moved by a set screw on the outside of the machine using a road brake cable attached to the lever of the disc brake. Figure 20 shows the brake actuation system. When the screw is turned, it brings the sliding block toward or away from the base block. The cable coming out of the other end of the sliding block is tensioned or loosened based on this adjustment, which activates the brake. There is a spring on the screw to ensure that the brake will return to its original position.

Shifter Subsystem

The only change made to the shifter subsystem was the use of a regular stem attached to a steel tube on the front of the machine. Road handlebars with road shifters are set up on the machine currently, but could easily be changed for mountain bike bars and shifters.

Housing and Controller Subsystem

Only one change was made to the housing and controller subsystem, which was the

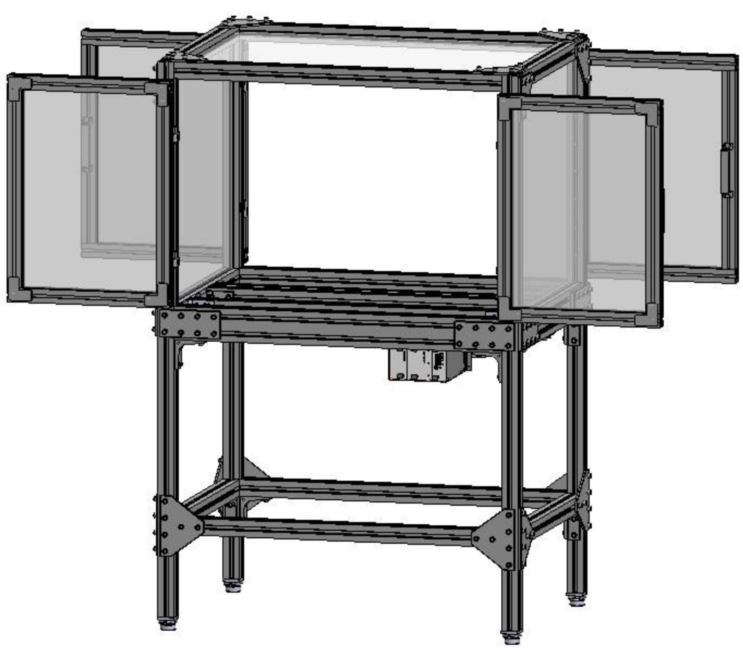

Figure 21. Small changes were made to the housing and controller subsystem.

removal of the crossbar at the top of the machine. This was going to be used to mount the linear actuator, which is not needed anymore. The dimensions of the housing were changed to take up the least amount of space while still being big enough to house the test components. The changes are illustrated in Figure 21. Figure 22 shows the final solid model of the entire

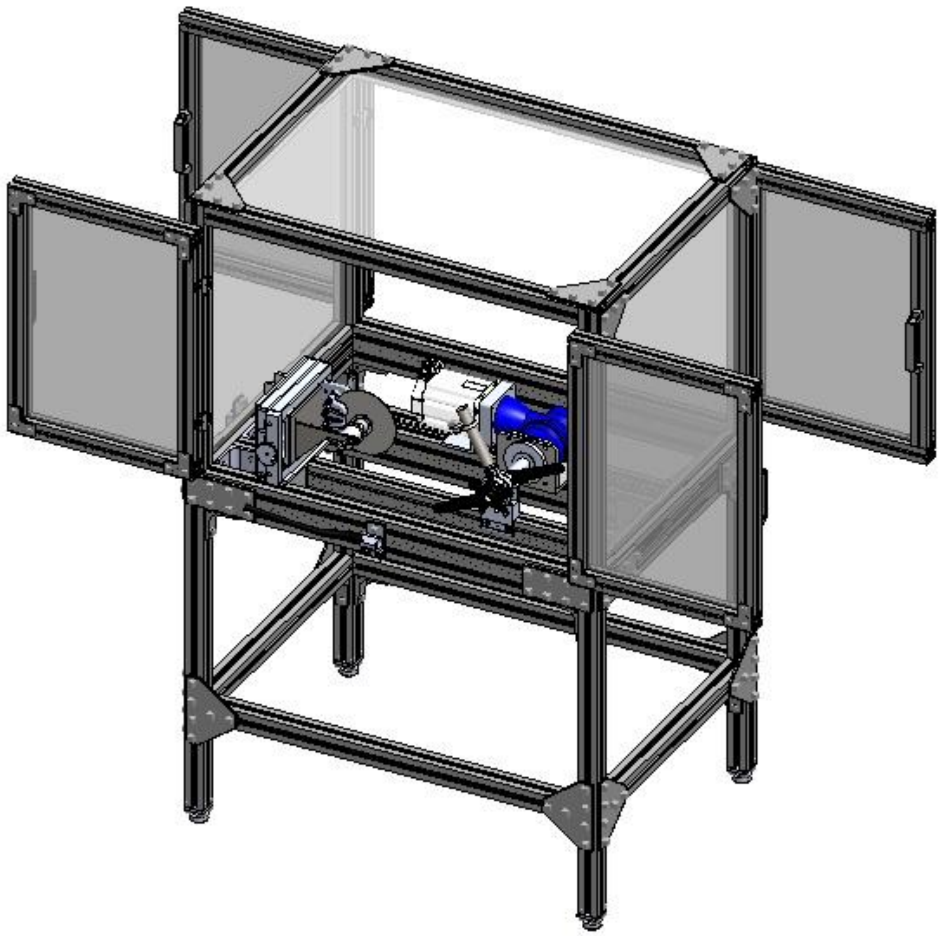

Figure 22. Final solid model of test machine.

machine. The final bill of materials for the test machine is detailed below in Table 2.

Table 2. Final bill of materials for test machine.

Al Extrude - 60x60x2000mm	4	Angle Bracket - 110x110x100 keyed	6
Al Extrude - 60x60x1200mm	4	Joining Plate - 220x160x8	8
Al Extrude - 60x60x1100mm	4	Joining Plate - 160x160x8	8
Al Extrude - 60x120x1200mm	2	Joining Plate - 220x110x8	12
Al Extrude - 60x120x848mm	2	Joining Plate - 84x84x4	16
Al Extrude - 120x120x1200mm	1	Polycarbonate sheeting (505x735mm)	4
Al Extrude - 50x100x1200mm	1	Polycarbonate sheeting (888x1238mm)	1
Al Extrude - 50x50x595mm	8	Polycarbonate sheeting (888x858mm)	2
Al Extrude - 50x50x715mm	8	Combi Hinge 50/60	8
Square Nut - M8	74	Handle L=179mm	4
Square Nut - M12	342	Leveling Mount - 3/8"x16tpi	4
Hex Nut - M10	4	Tolomatic Brake Caliper	1
Hex Nut - M12	16	Tolomatic Brake Rotor	1
Hex Jam Nut - M12	18	Velmex Slide	1
Hex Nut - 3/8	6	Adjustable Handles - M8x1.25tpix20mm	8
Fender Washer - M6	3	MPP Series Brushless Servo Motor	1
Rib Washer - M8	74	SPK 140 Series right angle gear reducer	1
Fender Washer - M10	16	10 ft. motor power cable	1
Rib Washer - M12	354	10 ft. encoder feeback cable	1
Fender Washer - M12	8	ACS MC4U Servo Drive Contoller System	1
Fender Washer - 5/16	4	MC4U Connector Kit	1
Fender Washer - 3/8	4	Al Angle Stock - 2.5"x2.5"X48"	1
Socket Head Bolt- 5/16x18x1in	4	Al Angle Stock - 2"x3"X48"	1
Flat Head Bolt - 3/8x16x3in	4	6061 Al Plate - 1"x2"x12"	1
Hex Head Bolt - 3/8x18x1.5in	2	6061 Al Plate - 0.5"x8"x36"	1
Socket Head Bolt - M4x6mm	4	6061 Bar - 1.5"x4"x12"	1
Socket Head Bolt - M6x15mm	2	6061 Bar - 4"x4"x12"	1
Socket Head Bolt - M6x55mm	1	6061 Rod - 16mmx6ft	1
Socket Head Bolt - M8x16mm	56	4130 Plate - 1/4"x12"x12"	3
Socket Head Bolt - M8x20mm	16	Steel 90 Degree Angle Plate - 4"x4"x3/8"x3ft	1
Socket head Bolt - M8x25mm	2	Steel 90 Degree Angle Plate - 6"x6"x1/2"x1ft	1
Socket Head Bolt - M12x25mm	324	6061 Plate - 3/8"x2.5"x12"	2
Socket Head Bolt - M12x30mm	8	6061 Plate - 5/8"x3"x12"	1
Socket Head Bolt - M10x50mm	6	4130 Plate - 1/4"x6"x36"	1
Socket Head Bolt - M10x60mm	2	General Duty Safety Switch	1
Hex Head Bolt - M12x35mm	6	30 Amp Fuse - Class RK5	3
M12x100mm Studs	8	Fuse Adapter Kits - 30 for 60 A size	3
M12x90mm Studs	2	10 Gauge Power Chord x 15 ft	1
Angle Bracket - 110x110x40 keyed	16	Emergency Shut-Off Button	1
Angle Bracket - 50x50x100 keyed	2	Angle Bracket - 110x110x100 keyed	6

Chapter 6 – Design Verification Plan

Due to the nature of this project, the test machine will be tested at the various stages of completion as it gets more complicated and the design gets closer to completion. Once the mechanical parts of the machine are assembled, a verification test will be performed to ensure that the mechanical system is functional. This will involve simple hand tests to make sure that all of the components clear the support structure and that the minimum tolerances and adjustability requirements can be achieved. Separately, the rotary motor and linear actuator will be tested with the controller and DAQ system to ensure that the system works and functions as an integrated system. Along the same lines, all the sensors will be individually tested to make sure that they function in the way intended for the test machine.

Once all the individual components have been tested, the system will be completely assembled and tested all together. This will be a much more exhaustive testing process than with the individual components. First, the machine will be entirely tested with the electronic components in place but being powered by hand. This will make sure that the sensors and DAQ system are able to pick up the information required. The next test will be to ensure that the drive components can automatically drive the machine, without attempting to record any data. Once these two separate parts have been independently verified, the whole test machine will be tested as a unit. This is where the final testing will take place. The DAQ system will be fully functioning and taking data from sensors while the electronic drive components drive the system. The drivetrain will be shifted through the range of gears successively to make sure that the program is able to collect data. The system will also be run at various design configurations to ensure the system works reliably with any and all adjustments being utilized and different loads and speeds at the drive mechanism. This test will be performed many times to make sure that reliable and useful data is being collected, and that all the requirements of the test machine are being met. This will be the main function of the machine, so this is the most important test that the machine will need to pass. Once these tests have been satisfactorily passed, the machine will be ready for use in SRAM's testing facility.

Unfortunately, the team was unable to complete the LabView programming portion of the project. However, the individual components were tested and achieved excellent results. The machine is ready to be programmed by SRAM to do whatever they need it to do. It has the potential to have all the functionality SRAM was looking for as well as being able to be adapted to have even more features. The machine functions as intended, just currently without the programming to run it the way SRAM intends to.

Chapter 7 – Management Plan

The key to a successful project is a well-defined management plan. Nick will be managing the programming aspect of the project with collaboration from Sam and Michael. Nick will also be the financial officer of the team and will document all monetary transactions of the project. Sam gained experience modeling with Solidworks at a summer internship so he will be managing the solid modeling portion of the project. He is also the main point of contact with the sponsor. Michael will be managing the manufacturing process of the design and the dynamic analysis of the machine. Individual responsibilities for this project will be flexible. Each

of the team members has similar abilities in computer programming, controls, and industrial manufacturing so teamwork will be the best method of approach for many of the tasks of this project.

Table 3. Management plan for SICK Drivetrain Testing team.

Team Member	Job Title	Task/Responsibilities
Nick Cox	Programmer CFO	Create/develop program in Labview Manage budget
Michael Polka	Manufacturer Design Analysis	Design for manufacturing: what to build and what to buy Layout of machine
Sam Shaffer	CAD Main Contact	Solid modeling Communicate with sponsor: relay information/questions, set-up meetings

With scheduling this project, particular emphasis was put on allowing plenty of time for testing and calibrating the final machine. To this end, the schedule for the first few months of 2013 will be packed with deadlines to ensure that CAD, manufacturing, assembly, and programming are done well before the hard deadline for the project. Since this is a test machine, it is key to make sure that it is able to perform reliable tests and collect all the necessary data. Many of the components being purchased for this project have very long lead times, and therefore must be ordered long before assembly and system testing. This means that the final design and analysis must be decided on quickly in order to not be behind schedule immediately.

Additionally, since the overall test machine has been divided up it can be designed, manufactured, and assembled concurrently with different subsystems. For example, since the housing and control subsystem will largely be made from pre-manufactured parts and require less design than the actual test stand, the housing and control subsystem can be finished before other systems are even done being designed. This will allow the design team to better gauge progress as well as get certain parts of the test machine done as quickly as possible to mitigate downtime and maximize efficiency.

Chapter 8 – Conclusions and Recommendations

The SRAM Loaded Shift Tester project turned out incredibly well, with nearly all of the goals set forth being met. The final product produced by the SICK Drivetrain Testing team is a fully-functioning test machine that will provide invaluable design information about the performance of bicycle chains, chainrings, and front derailleurs.

The main component of the project that was not completed was the programming of the test machine in LabView. Due to a series of technical issues and miscommunications, the design team had a great deal of difficulty interfacing the machine with a computer. This led to a severe setback in testing the individual components of the machine, which needed to be done before any programs could be tested. The team was able to complete enough with the programming to test the function of all the components and ensure that the all the machine's

components work together smoothly. While it is unfortunate that the team was not able to meet this goal, the machine is in the position to be programmed and run immediately by experts with LabView.

For the future, the team has several recommendations that could be used to greatly increase the utility of the test machine. The first is that the machine should be set up to be controlled by LabView. This will allow the machine to get much more significant data than what can be gleaned from simply running the machine at a constant speed and shifting through the drivetrain. Another recommendation is that the machine be set up to run off of automatic shifting controlled by the LabView program. This will allow more precise data to be collected about the time required to make a shift and the force required to make that shift. The addition of a high-speed camera would also be useful in adding to the quality of the data collected. If a camera were set up such that it was recorded alongside torque and position data for the machine, the video could help the designers see what is going on during the test much more clearly. Making these updates to the machine will greatly increase the functionality of the machine and allow the designers at SRAM to gain more insight into the problems associated with their designs.

In conclusion, this project was very informative and useful for expanding the knowledge of the SICK Drivetrain Testing team. From the initial ideation and background research all the way through final design and manufacturing, the team gained valuable experience in mechanical design. The team was forced to gain practice in real-world design and manufacturing techniques, as well as working with vendors and sales engineers to specify components for something none of the team had any experience in. The team learned a great deal about electronics and interfacing computers with controllers and electromechanical devices frequently used by mechanical engineers. Additionally, the team improved their skills in technical communication through the many reports and presentations required throughout the design and manufacturing process. This project increased the understanding of many engineering concepts for the team and was an incredible experience overall.

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Appendix A: Schedule

A preliminary schedule for the project was created (Figure 14 below) while keeping in mind the importance of allowing adequate time for system testing. An emphasis was put on finishing all modeling and prototyping early in order to get the final test machine assembled and ready for calibration and testing with plenty of time before the final due date at the Senior Project Expo.

	Task Mode	Task Name	Duration	Start	Finish
1		Conceptual Design Report	18 days	Tue 11/6/12	Thu 11/29/12
2		Analysis, Drawings, and BOM Review	3 days	Tue 1/8/13	Thu 1/10/13
3		Test Plan Development	6 days	Thu 1/10/13	Thu 1/17/13
4		Order Long Lead-time Materials	6 days	Thu 1/17/13	Thu 1/24/13
5		Practice Critical Design Review	19 days	Mon 1/7/13	Thu 1/31/13
6		Individual Ethics Memo Topic	6 days	Tue 1/29/13	Tue 2/5/13
7		Design Report	22 days	Mon 1/7/13	Tue 2/5/13
8		Critical Design Review	24 days	Mon 1/7/13	Thu 2/7/13
9		Individual Ethics Memo	6 days	Tue 2/5/13	Tue 2/12/13
10		Team Ethics Presentation	8 days	Tue 2/12/13	Thu 2/21/13
11		Manufacturing and Test Review	11 days	Thu 2/21/13	Thu 3/7/13
12		End of Quarter Report	6 days	Thu 3/7/13	Thu 3/14/13
13		Update Memo to Sponsor	9 days	Tue 4/2/13	Fri 4/12/13
14		Senior Project Expo	1 day	Thu 5/30/13	Thu 5/30/13
15		Final Report	49 days	Tue 4/2/13	Fri 6/7/13
16		Finish CAD	25 days	Mon 1/7/13	Fri 2/8/13
17		Finish assembly	85 days	Mon 1/7/13	Fri 5/3/13
18		Finish machining	75 days	Mon 1/7/13	Fri 4/19/13
19		Finish programming	85 days	Mon 1/7/13	Fri 5/3/13
20		Finish testing	16 days	Sat 5/4/13	Fri 5/24/13
21		Order components	100 days	Mon 11/26/12	Fri 4/12/13
22		Finish poster	45 days	Mon 3/25/13	Fri 5/24/13
23		Check tolerances, alignment, rigidity of system	90 days	Mon 1/7/13	Fri 5/10/13
24		Prototype	50 days	Mon 1/7/13	Fri 3/15/13
25		Teams Formed	1 day	Mon 9/24/12	Mon 9/24/12
26		Project Presentations	3 days	Tue 9/18/12	Thu 9/20/12
27		Project Preference Form due	1 day	Fri 9/21/12	Fri 9/21/12
28		Letter of Introduction to Sponsor	3 days	Tue 9/25/12	Thu 9/27/12
29		Project Proposal	6 days	Thu 10/11/12	Thu 10/18/12
30		Meet Sponsor	5 days	Mon 9/24/12	Fri 9/28/12

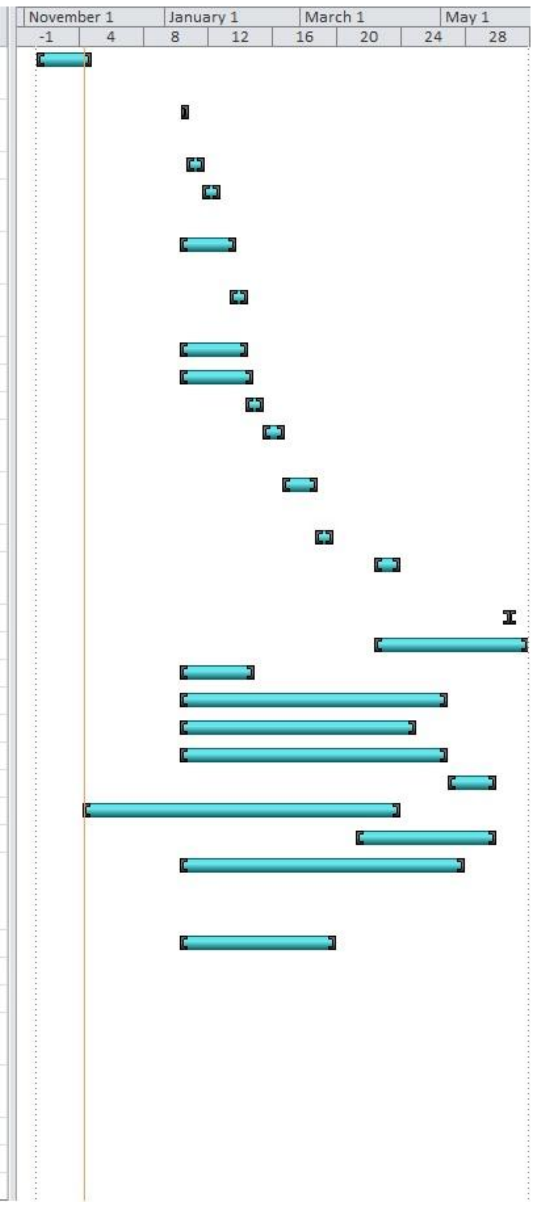

Figure 23. Gantt chart detailing preliminary schedule for SRAM shift test machine project.