Magneto Rheological Damper Requirements Document

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I. Problem Definition

The primary objective of this project is to determine the suitability and feasibility of using magneto rheological damper technology as part of an actively controlled bicycle suspension system. The goal of this investigation is to create a laboratory system that demonstrates the ability to influence damping characteristics from external computer controls and to create a conceptual design of the hardware/software/algorithms that would be needed for prototyping.

There are over 5 million Mountain Bikes (MTBs) sold each year in this country alone. The suspension system is a significant driver of overall performance and unit cost. Any improvements that enhance performance or reduce cost would have a huge market potential. Of particular interest is the use of magneto rheological damper technology as part of a MTB suspension system. Magneto rheological (MR) fluid is a magnetic fluid that changes viscosity in the presence of a magnetic field. An electromagnet is used to change the viscosity of MR fluid. MR fluid is used as a damper in shock absorbers. When MR fluid is brought into a magnetic field, the metal particles in the fluid are aligned according to the magnetic field lines [1]. The stronger the magnetic field, the higher the viscosity of the MR fluid.

Figure 1[2][3] shows a basic depiction of the various parts of the system.

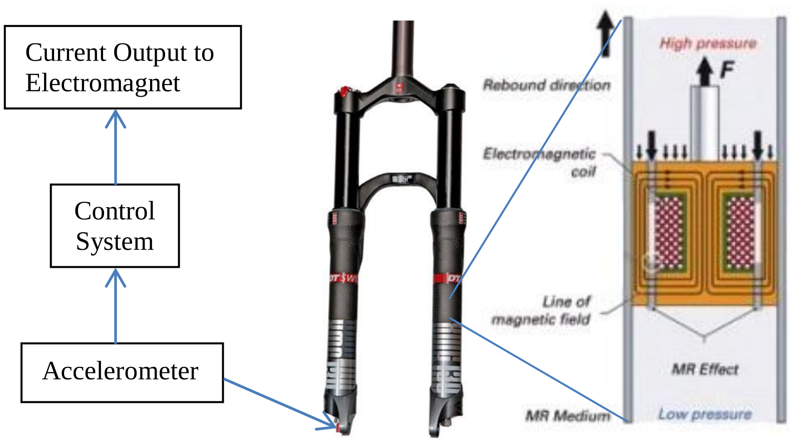

Figure 1. Block Diagram of the System

Figure 1 depicts an accelerometer placed at the base of the fork near the front wheel. Impulses detected by the accelerometers are sent to a control system. The control system is a microcontroller with firmware programmed into it. The firmware consists of algorithms which interpret information from the accelerometer. The algorithms will determine how much current to send through the electromagnet. The

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electromagnet is used to control the viscosity of MR fluid. The viscosity of MR fluid will determine the damping characteristics of the suspension system.

II. RESEARCH SURVEY RESULTS

This project and report will address suspension systems regarding mountain bikes (MTBs). The primary purpose of the MTB suspension system is to assist the rider in retaining maximum control by maintaining wheel contact with the ground when the bike is ridden over uneven terrain. The system does this by absorbing the energy (shock) generated when the bike encounters an obstacle in order to prevent that energy from being transferred to the rider. The shock absorbers consist of two parts; a spring and a damper. The spring (which can be either a conventional wire coil or pressurized air) provides the force necessary to return the system to the extended (retracted) position. The damper is the mechanism that dissipates the generated kinetic energy and flattens shock impulses. Each system is housed in a separate stanchion (or fork arm) of the mountain bike fork. Figure 2 shows the basic physics involved in a spring/mass damper system.

Part A shows the effects of a spring oscillating harmonically in time in response to an applied force. The dampers smooth out the spring oscillations, as seen in part B.

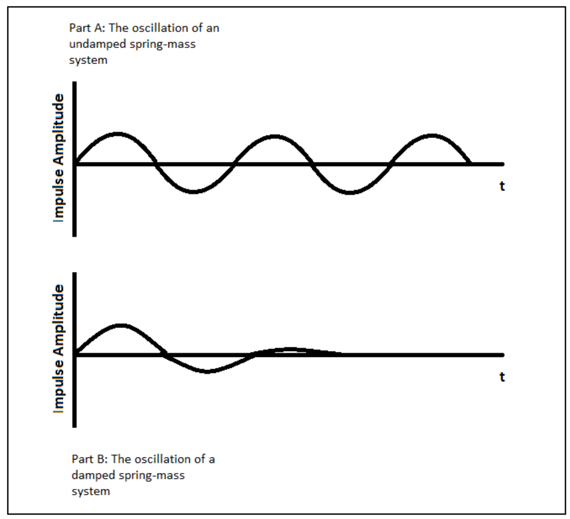

Figure 2. Oscillation of an undamped (Part A) and damped (Part B) spring-mass system over time.

Many types of dampers have been used in MTB suspension systems. The most basic type is a simple friction damper which uses a stationary cylinder that rubs on the station tube as it moves in response to an applied force. The type most commonly used dampers are oil dampers. Oil dampers convert energy to heat through the frictional forces that occur when hydraulic fluid is forced through a constricted orifice. Oil damper configurations used on mountain bikes include: mono-tube oil dampers and twin-tube oil dampers. The state-of-the-art MTB dampers are sophisticated, well designed devices that include many intricate mechanical valves in order to achieve the desired damping characteristics. Advanced automotive suspension systems now use MR fluid in their dampers. MR fluids can be used in conjunction with electrical sensors to provide real-time optimization of the damper characteristics. Because of these characteristics, it would be desirable to use MR fluids in MTB suspension applications as well.

a) Coil Spring/Air Spring

Coil springs are typically constructed from steel; however, titanium is sometimes used in MTB applications in order to save weight. Coil springs can be designed to achieve a linear spring rate (change in spring force divided by change in distance), or they can be configured to have a progressive spring rate. For a linear spring rate, the force required to compress a coil remains the same throughout the stroke of the spring, whereas a progressive spring requires an exponentially increasing force to move through its stroke. An air spring is a sealed chamber filled with compressed air. When acted on by a force, a piston inside the chamber further compresses the air to arrest the applied force and reverse the motion of the piston. Air springs possess a progressive spring rate; however, by increasing the volume of the air cylinder a more

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linear response can be achieved. Coil springs typically provide greater durability and responsiveness compared to air springs. Air springs offer greater adjustability and lighter weight.

The spring provides the restoring force needed to return the system back to the retracted (uncompressed) position. The rate at which it retracts is a function of the spring rate and the amount of rebound damping applied. Too little rebound damping and the fork will retract too quickly, possibly bouncing the wheel off the ground, throwing the rider off balance, or providing poor traction. Too much rebound damping and the fork will not open fast enough to respond to the next impact and will give a harsh ride[4].

Spring sag is a term that defines the distance the suspension compresses due to rider weight. Sag is needed to allow for overshoot that occurs as the suspension settles back to its extended position. Optimal sag is typically 20-25% of the full travel of the suspension. Sag is adjustable based on rider weight and preference. Sag is controlled by spring pre-load for a coil spring and air pressure for an air spring system[4]. Since spring rate is an inherent property of a particular coil spring design, the coil must be replaced in order to alter spring rate. Several suspension systems offer preload adjustments which allow the rider to manipulate rebound damping and sag by turning a knob. Air springs adjust rebound rate and sag through air pressure. More air pressure equates to a stiffer shock, which means a faster rebound rate and less sag. A shock pump is used to adjust air pressure in an air shock.

b) Mono-Tube Oil Damper

An image of a mono-tube oil damper can be seen in Figure 3. Mono-tube dampers consist of a single cylinder filled with oil and high pressure gas. The cylinder also houses a piston with valves. During compression, oil is forced through the valves on the piston. Kinetic energy is converted into heat due to the friction of the oil flowing through the valves. A floating piston provides a physical barrier between the damper's oil and the high pressure gas needed for shaft displacement [5]. Nitrogen, which is stable under high heat, is often used as the low pressure gas.

c) Twin-Tube Oil Damper

An image of a twin-tube oil damper can be seen in Figure 3 [6]. Twin-tube dampers consist of an inner and outer cylinder. The inner tube is filled with oil. The outer tube is a reservoir which is partly filled with oil and low pressure gas. The inner tube also houses a piston with valves. During compression, oil is forced through the valves on the piston. Kinetic energy is converted into heat due to the friction of the oil flowing through the valves. Another base valve allows oil to flow from the inner to outer tube due to oil displacement from the piston rod. Hard working dampers create high temperatures. Like mono-tube dampers, Nitrogen is often used as the low pressure gas. During extension, the gas forces oil in the outer tube back into the inner tube. At high temperatures, damper oil begins to foam, which causes the oil to become more viscous. Foaming is especially apparent with twin-tube dampers. The high pressure in mono-tube dampers prevents damper oil from foaming. The Nitrogen helps to prevent foam from forming with twin-tube dampers.

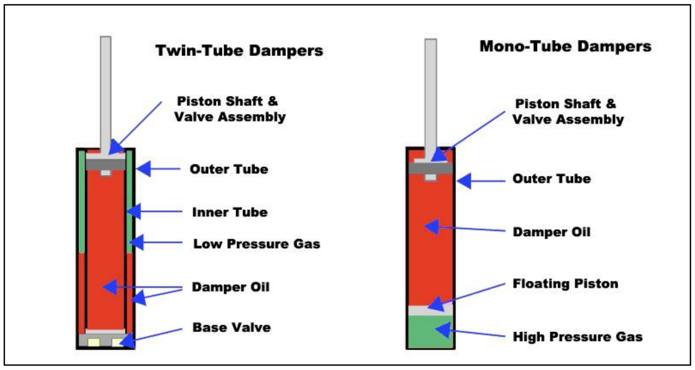

Figure 3. Twin-Tube vs Mono-Tube Dampers

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d) Oil Damper Valve Assemblies

Valves regulate oil flow through orifices in the piston head. Many valving schemes exist for dampers. Shim stacks are primarily used as valves for MTB dampers. A shim stack is a series of thin washers which constrict or increase the amount of oil allowed through a damper orifice. Figure 4 [7] shows how a shim stack works.

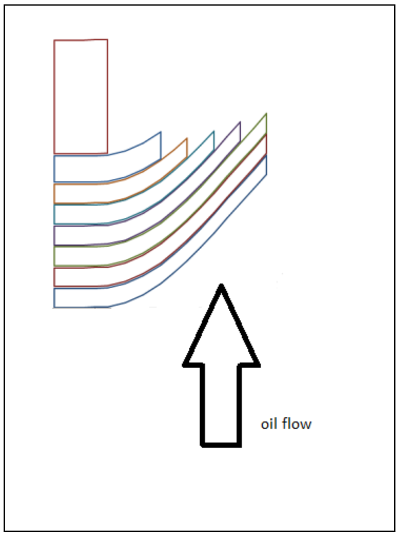

Figure 4. Shim Stack Behavior Due to Oil Flow

At low speed collisions, suspension is stiff and shim stacks remain flat, constricting oil flow through an orifice. At high speed collisions, suspension is soft and shim stacks fold open, allowing more oil to flow through an orifice. Shims can be bought with various widths and diameters. Different size shims generate varying valve control. Separate shim stacks control compression and rebound damping.

e) Mountain Bike Suspension Systems

There are hundreds of different damper and spring combinations available to MTB riders. MTB suspension systems range from tens to thousands of dollars. Quality MTB suspension systems are available for cheap; however, low end systems typically do not offer variability for rider preference. High end systems offer adjustments for compression/rebound damping, sag, ride height, lockout and many other modifications. Suspension systems such as Cannondale’s Simon attempt active electronic control over suspension characteristics.

f) Cannondale Simon

Simon is a prototype active suspension system for mountain bikes from Cannondale. Simon is an electronically controlled twin-tube oil damper suspension system. Simon damper is simple from a mechanical standpoint, consisting of a single solid piston pushing oil back and forth through just one orifice [8]. A retractable pin, controlled by a fast acting Cannondale-exclusive linear stepper motor, adjusts the size of the port, which can go from full-open to full-closed in just six milliseconds [8].

The heart of the system is a CPU, which analyzes and processes information from sensors located at the base of the fork [9]. The accelerometer near the axle of the front wheel detects ground conditions. The accelerometer information is processed by the CPU which sends commands to the stepper motor. The CPU processes the information coming from the sensors at a rate of 500 times per second [9].

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Simon has five preset riding modes available: mountain, cross country, downhill, travel management, and lockout. The Mountain mode is very similar to a standard mountain bike damper. Cross country mode is a stiff suspension designed for racing. Downhill mode is a soft suspension which provides the largest amount of travel available. Travel management mode is used when climbing hills. The amount of travel in the front shock is decreased so as to reduce the weight applied on the rear of the bike. Lockout mode forces the shock to become rigid, and is used for riding on paved roads where peddle bob is unwanted. Lockout mode can still react to various road conditions such as potholes, and increases damping as needed.

Users interact with Simon through a switch on the handlebar and an LCD screen at the top of the fork. Different riding modes can be selected while riding.

g) Magnetorheological Fluid

MR fluid is a smart fluid that is finding its way into our everyday lives. MR fluid is currently being used in devices such as clutches, brakes, dampers, and even body armor. Uses for MR dampers include vibration and shock impulse elimination in appliances such as washers and dryers, seats, airplane engines and automobile suspension. MagneRide is a cutting edge suspension system which uses MR fluid as its damper oil.

h) MagneRide

Car manufacturers that currently use MR fluid in suspensions systems include GM, Honda, BMW, Ferrari, Audi, and many others. Aside from BMW (which uses a proprietary version of MR damping), other car manufacturers which use MR damping essentially use the same system, MagneRide. MagneRide is a semi-active suspension system utilizing MR fluids. Developed by the Delphi Corporation, the MagneRide debuted on the Cadillac Seville STS in 2002. MagneRide technology is now owned by Beijing West Industries (BWI). Figure 5 [3] shows the basic structure of the MagneRide MR damper.

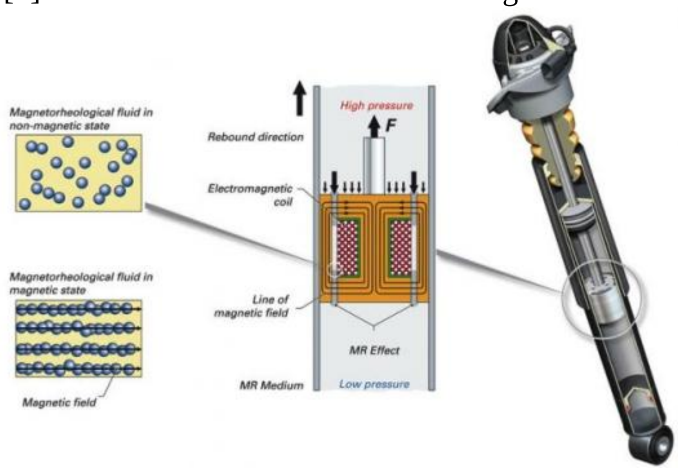

Figure 5. MageneRide MR Damper

Seen in Figure 5 are the narrow channels, which MR fluid flows through. When the electromagnetic coils are not powered (when no magnetic field is present), MR fluid is free to flow through the channels, as the fluid is in a non-magnetic state. With the electromagnetic coils turned off, MR fluid easily flows through the channels, generating a softer response from the shock. When the electromagnetic coils are powered, a magnetic field is produced with magnetic flux lines as shown in Figure 5. In the presence of a magnetic field, MR fluid enters a magnetic state. The iron particles in MR fluid bond in the direction of the magnetic flux lines. The bonds of the iron particles impede the flow of MR fluid, generating a stiffer response from the shock.

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i) MR Fluid as Damper Oil in MTB Suspension

As seen with MagneRide, MR dampers are already being used in automotive applications. MR dampers could also be used in MTB applications. MR fluid could provide a simple, elegant solution to a mountain bike damper industry that has spent hundreds of millions of dollars designing complex oil dampers using shim stacks and other mechanisms to control oil flow. Complicated valving is not needed with MR dampers; instead, an electromagnet is used to control oil flow. An electromagnet allows infinite adjustability. An electromagnet and sensors detecting uneven terrain can instantly, in real time, actively control suspension systems.

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III. REQUIREMENTS AND SPECIFICATIONS

Mechanical

The MR damper system should fit in a standard mountain bike fork with a 26 inch wheel. The entire suspension system should be light weight. No toxic or hazardous materials shall be used in the design. System failures shall be considered and precautions must be taken in order to mitigate harm to the user.

Table 1. Mechanical Requirements

Weight	Less than 6 lbs (total fork weight).
Wheel Spacing	110 mm.
Steerer Tube Diameter	1.125 in.
Steerer Tube Length	9 in minimum.
Suspension Travel	5 – 6 in (125 – 150 mm) minimum.
Wheel size	26 in diameter.
Axel Size	15 mm thru axel design.
Fork Tube Diameter	32 – 36 mm.
Spring	Air spring.
Brake Mounting	Post style disc brake mount.
Operating Loads	25 – 85 lbs.

Electrical

The electronics shall utilize accelerometers to sense operating forces, determine optimal damping, and generate a signal to control the magnetic flux density across the damper. The electronics should be small enough to be mounted on the bicycle's handlebars. The microcontroller should consume little power. The microcontroller shall be capable of processing sensor inputs and providing control signal outputs at a high rate. Electronics shall be reprogrammable via external interface connection. Users shall have the option to select one of three modes of operation (soft, medium, firm). Electronics shall provide external controls for both compression and rebound damping. The electronics system shall be capable of driving a low impedance load.

Table 2. Electrical Requirements

Power	5 W max.
Power Source	12 +/- 2.0 Vdc battery supply.
Package Size	4 x 8 x 2 in.
Update Rate	Less than 1 ms.
Accelerometer range	-1 to 10 g.
Drive current	100mA at less than 10 ohms.
Accuracy	TBD.

Environment

The system should be capable of withstanding the environments to which a mountain bike is subjected.

Table 3. Environmental Requirements

Temperature	32 – 120 F.
Moisture	30 – 100% relative humidity.
Water	1 ft for a duration of 10 s.
Shock	TBD
Vibration	TBD

Documentation

Documentation package shall include: all drawings, sketches, schematics, part numbers, and software/firmware code needed to reproduce the design.

Table 4. Project Summary

Design Description	• Description of overall system design. • Must show all calculations and derivations pertinent to the development of the system.
Design Trade-offs (related to cost and performance)	• Should include any ideas for future design improvements.
Damper Mechanical Drawing	• Show all dimensions and tolerances critical to manufacturing. • Show all materials used.
Shock Fluid Specifications	• Complete material specifications including lists of manufacturers.
Electrical Schematics	• Circuit layout including part numbers of all components.
Software/Firmware Design	• Flow charts of logical processes. • Details of algorithm implementation.
User Guide	• Description of use. • Information on reprogramming or uploading of control settings.

Testing

Developmental testing of the system shall be performed on a test platform suitable for evaluation of key performance criteria. The platform should have the ability to measure and plot forces imposed on the suspension system in order to determine damping effectiveness.

Table 5. Testing Equipment

Test Equipment Setup	• Description of the equipment used including a block diagram of the test system. • The description must also address all necessary safety precautions.
Test Equipment Capability	• Specifications defining amplitude and frequency range. • The display of collected data and measurement accuracies. • Photos of the system should also be included.
Test Report	• A description of the development testing performed. • Results obtained.

General: TBD

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