Innovative Designs for Magneto-Rheological Dampers

James Poynor

Advanced Vehicle Dynamics Laboratory

Virginia Polytechnic Institute and State University

Audience of Thesis

The primary audience for this thesis will be my graduate advisory committee. A secondary audience may consist of students that are involved in the field of magneto-rheological (MR) damper design.

Summary of Thesis

This thesis will present the results of evaluating several different MR damper designs and will also make recommendations for the design of new MR dampers. The following excerpt is Chapter 1.

Table of Contents

Chapter 1
Introduction

The main purpose of this chapter is to introduce the topic of magneto-rheological (MR) dampers to the reader. Also presented is an explanation of the mechanism through which MR fluid works. Lastly, the project objectives and the approach taken to evaluate different MR damper designs are discussed.

1.1 An Overview of Magneto-Rheological Dampers

In recent years, manufacturers have shown an increased interest in MR devices. For instance, the Lord Corporation has been developing MR fluid and manufacturing MR truck seat dampers for a number of years now. These seat dampers are retrofits that replace hydraulic seat dampers that are original equipment on many large commercial trucks. Lord Corporation's truck seat dampers are arguably the most successful commercial MR dampers to date.

In addition to truck seat dampers, other commercial MR dampers will be available in the near future. General Motors, for instance, has announced that an MR damper suspension system will be available on certain 2003 Cadillac models. MR dampers are not restricted, however, to vehicle applications. Recently, the military has shown interest in using MR dampers to control gun recoil on Naval gun turrets and field artillery. Another area of study that has incorporated MR dampers is the stabilization of buildings during earthquakes. This increase in commercial interest is largely due to the success of research projects and through the efforts of Lord Corporation, which is a leader in the field of MR devices.

Magneto-Rheological Fluid. MR fluid is composed of oil and varying percentages of iron particles that have been coated with an anti-coagulant material. When unactivated, MR fluid behaves as ordinary oil.When exposed to a magnetic field, micron-size iron particles that are dispersed throughout the fluid align themselves along magnetic flux lines. This reordering of iron particles can be visualized as a large number of microscopic spherical beads that are threaded onto a very thin string. One can picture this thin string stretching from one magnetic pole to the other and perpendicular to each paramagnetic pole surface. In this analogy, the spherical beads represent iron particles and the string represents a single flux line. One can picture many of these strings of beads placed closely together much like the bristles of a toothbrush. Once aligned in this fashion, the iron particles resist being moved out of their respective flux lines and act as a barrier to fluid flow.

MR fluid can be used in three different ways, all of which can be applied to MR damper design depending on the damper's intended use. These modes of operation are referred to as squeeze mode, valve mode, and shear mode. A device that uses squeeze mode has a thin film (on the order of 0.020 in.) of MR fluid that is sandwiched between paramagnetic pole surfaces as shown in Figure 1. An MR fluid device is said to operate in shear mode when a thin layer (≈ 0.005 to 0.015 in.) of MR fluid is sandwiched between two paramagnetic moving surfaces. Shear mode (see Figure 2) is useful primarily for dampers that are not required to produce large forces and for clutches and brakes. The last mode of MR damper operation, valve mode (see Figure 3), is the most widely used of the three modes. An MR device is said to operate in valve mode when the MR fluid is used to impede the flow of MR fluid from one reservoir to another. With the exception of a single hybrid MR damper design, all of the dampers that this project has been involved with operate in the valve mode.

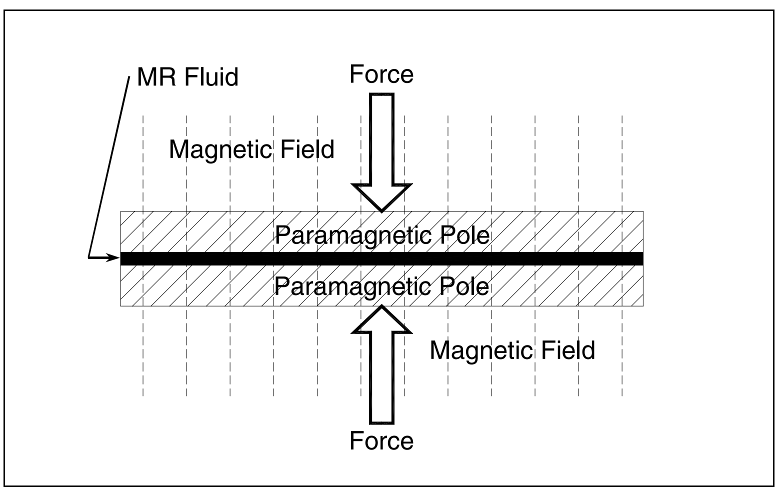

Figure 1. MR fluid used in squeeze mode.

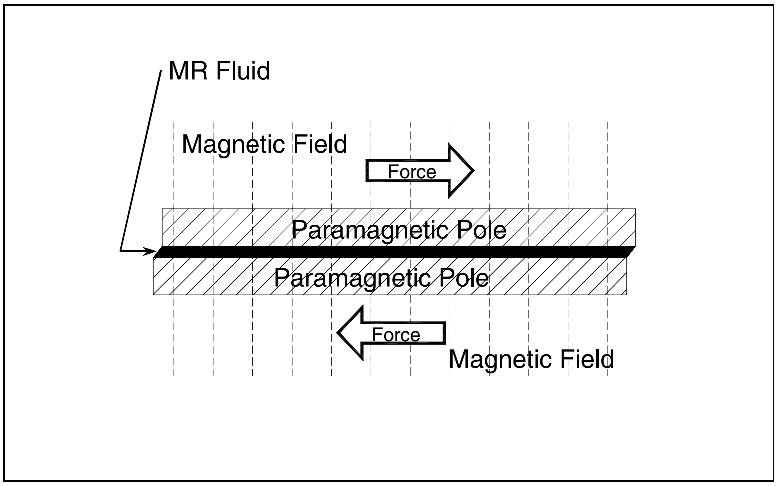

Figure 2. MR fluid used in shear mode.

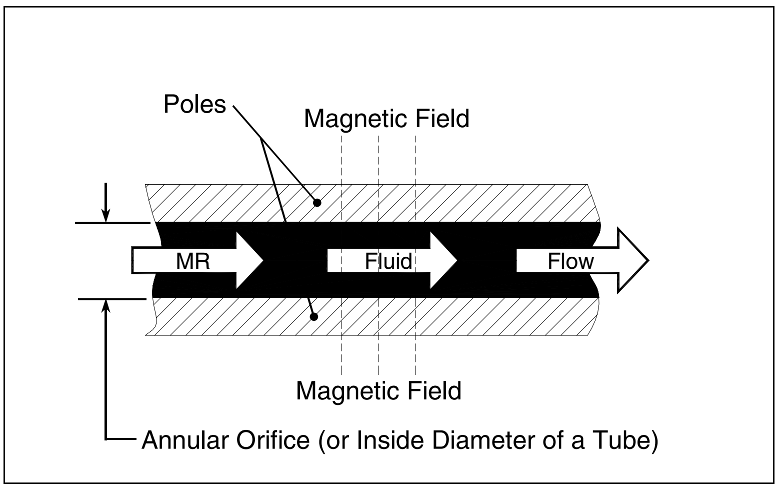

Figure 3. MR fluid used in valve mode.

When MR fluid is used in the valve mode, the areas where the MR fluid is exposed to magnetic flux lines are usually referred to as "choking points" (see Figure 4). In the case of the damper depicted in Figure 4, MR fluid restricts the flow of fluid from one side of the piston to the other when the fluid is in the vicinity of the "choking points" shown. Varying the magnetic field strength has the effect of changing the apparent viscosity of the MR fluid. The phrase "apparent viscosity" is used since the carrier fluid exhibits no change in viscosity as the magnetic field strength is varied. Upon exposure to a magnetic field, the MR fluid as (a whole) will appear to have undergone a change in viscosity. As the magnetic field strength increases, the resistance to fluid flow at the choking points increases until the saturation point has been reached. The saturation point is the point where any increase in magnetic field strength fails to yield an increase in damper resistance. This resistance to movement that the iron particles exhibit is what allows us to use MR fluid in electrically controlled viscous dampers.

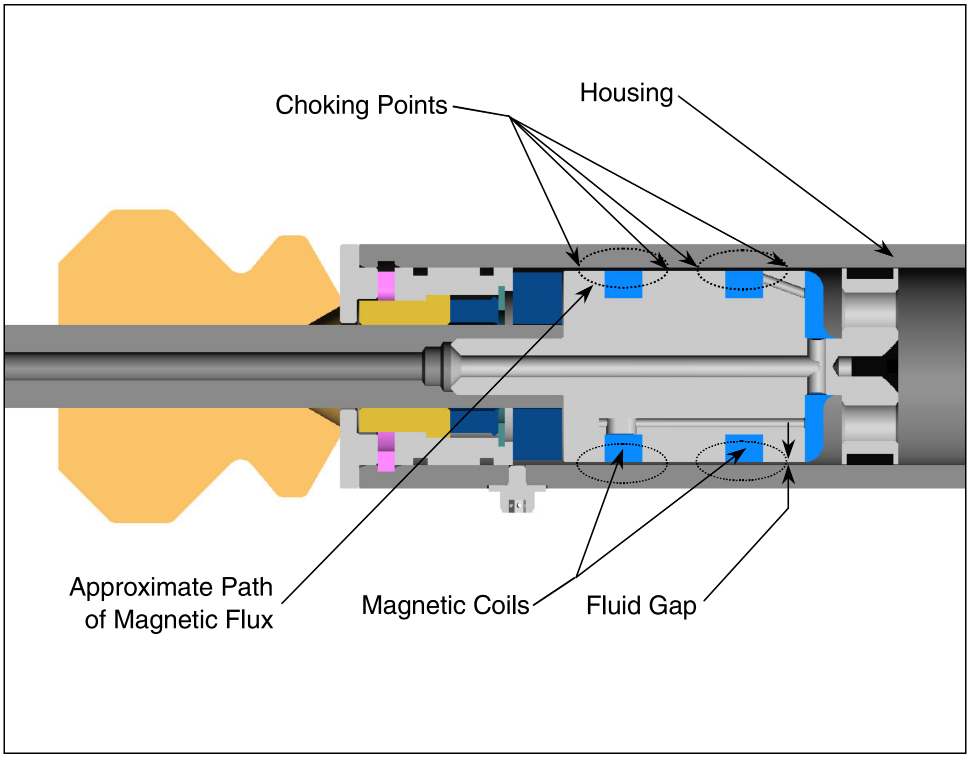

Figure 4. Typical MR damper.

Monotube and Twin Tube Magneto-Rheological Dampers. A monotube MR damper (see Figure 5) is one that has only one reservoir for the MR fluid and also has some way to allow for the change in volume that results from piston rod movement. In order to accommodate this change in reservoir volume, an accumulator piston is usually used. The accumulator piston provides a barrier between the MR fluid and a compressed gas (usually nitrogen) that is used to accommodate the necessary volume changes.

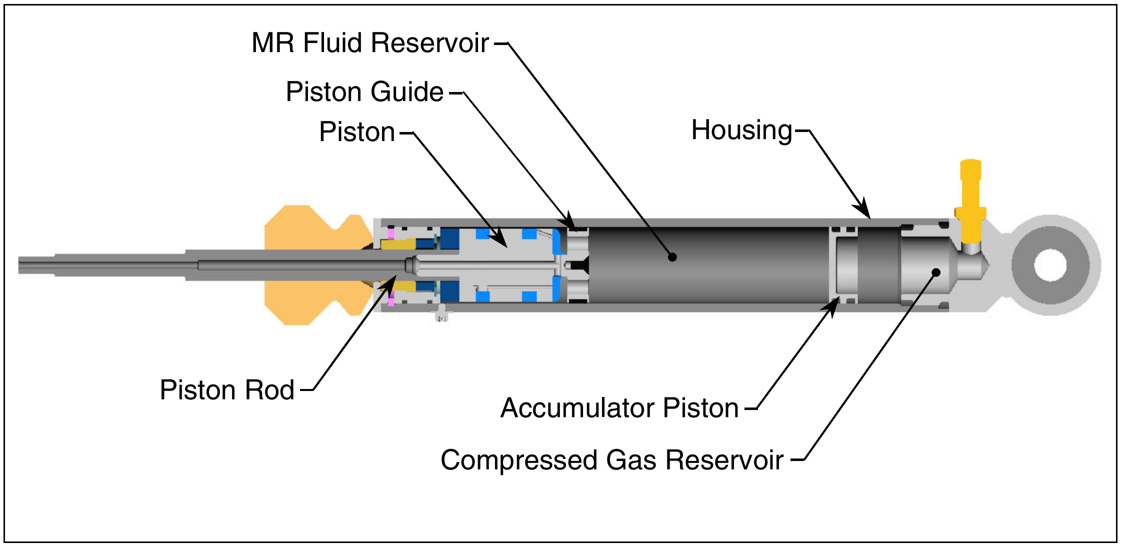

Figure 5. Monotube MR damper section view.

The twin tube MR damper is one that has two fluid reservoirs, one inside of the other. This configuration, which can be seen in Figure 6, has an inner and an outer housing. The inner housing guides the piston/piston rod assembly just as the housing of a monotube damper does. This inner housing is filled with MR fluid so that no air pockets exist. To accommodate changes in volume due to piston rod movement, an outer housing that is partially filled with MR fluid occurs. In practice, a valve assembly called a "foot valve" is attached to the bottom of the inner housing to regulate the flow of fluid between the two reservoirs (see Figure 7). As the piston rod enters the damper, MR fluid flows from the inner housing into the outer housing through the compression valve that is attached to the bottom of the inner housing. The amount of fluid that flows from the inner housing into the outer housing is equal to the volume displaced by the piston rod as it enters the inner housing. As the piston rod is withdrawn from the damper, MR fluid flows into the inner housing through the return valve.

In order for a twin-tube MR damper to function properly, the compression valve must be stiff relative to the pressure differential that exists between either side of the piston when it is in operation. The return valve must be very unrestrictive so that as little resistance to fluid flow as possible is provided. The damper should function properly as long as the following conditions are met: (1) the valving is set up properly; (2) MR fluid settling is not a problem; and (3) the damper is used in an upright position. With this type of MR damper, keeping the iron particles (which are an integral part of MR fluid) in suspension is a major concern since these iron particles can settle into the valve area and prevent the damper from operating properly. All MR dampers are affected by MR fluid settling, but this problem is particularly prevalent in the twin tube variety.

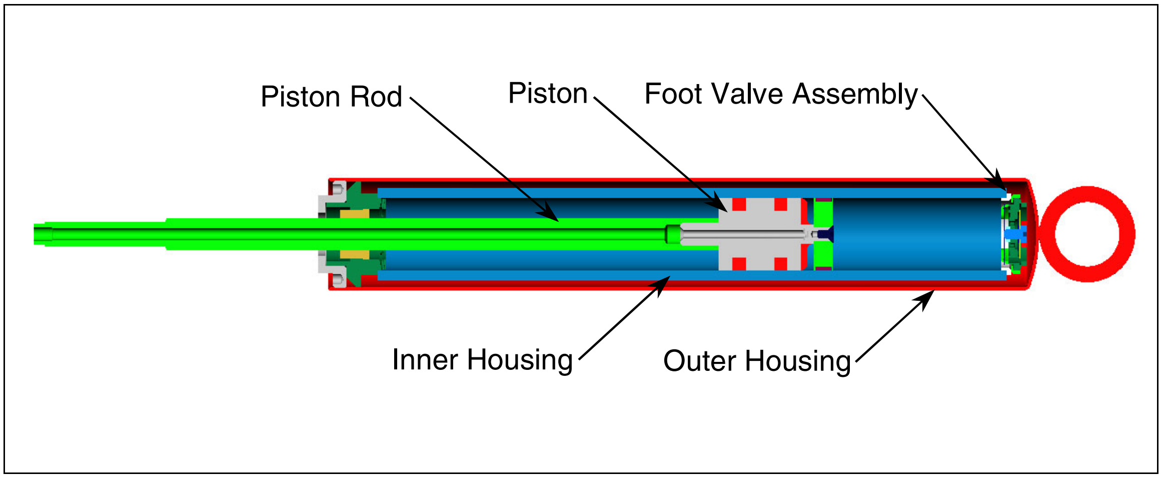

Figure 6. Twin tube MR damper.

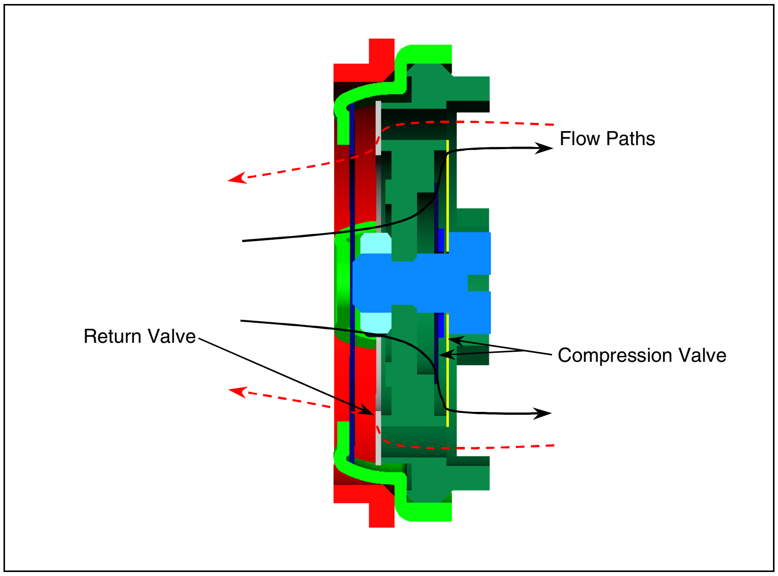

Figure 7. Detail of foot valve.

Other Magneto-Rheological Damper Designs. The last two designs are the double-ended MR damper and the MR piloted hydraulic damper. The double-ended MR damper (see Figure 8) is one that has piston rods of the same diameter that protrude through both ends of the damper. Since there is no change in volume as the piston rod moves, the double-ended damper does not require an accumulator or other similar device. Double-ended MR dampers have been used for bicycle applications, gun recoil applications, and for stabilizing buildings during earthquakes.

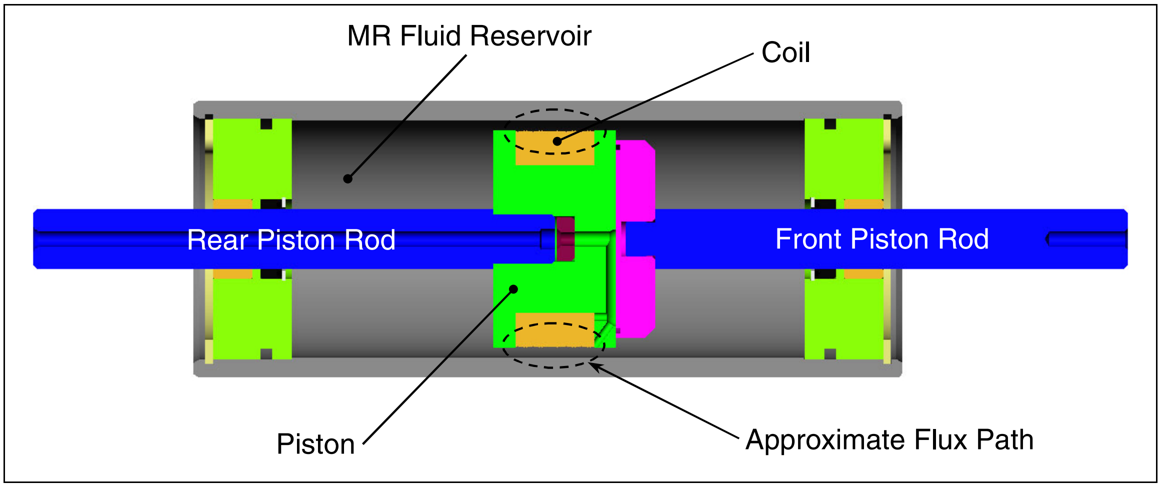

Figure 8. Double-ended MR damper.

The last type of MR damper that will be mentioned is the MR piloted hydraulic damper (see Figure 9). MR piloted hydraulic dampers are hybrid dampers in which a small MR damper controls a valve that, in turn, is used to regulate the flow of hydraulic fluid.

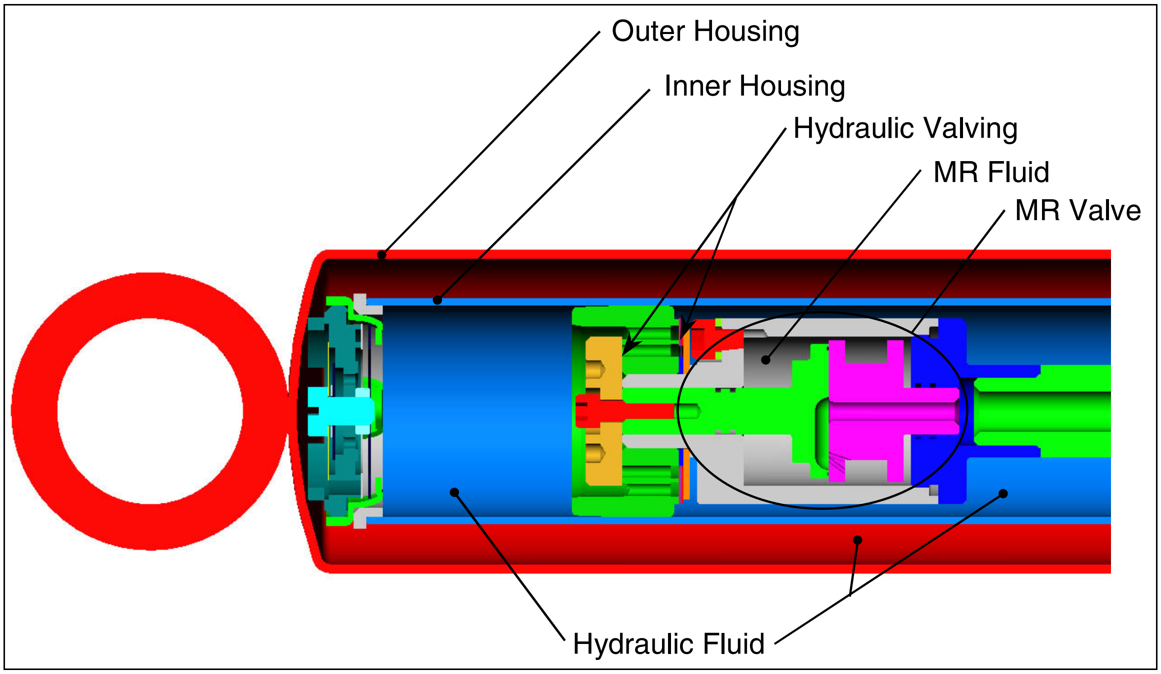

Figure 9. MR piloted hydraulic damper.

1.2 Project Objectives

The primary objectives of this research were as follows: (1) to study different designs that are commonly used for MR dampers; (2) to recommend new designs that were able to improve the performance of existing MR dampers; and (3) to provide recommendations for the effective design and fabrication of MR dampers. To accomplish these goals, several MR dampers were designed, built, and tested to determine their suitability and performance for specific applications.

1.3 Approach

The approach used to satisfy the previously stated objectives was to design, build, and test MR dampers for automotive and gun recoil applications. To explore the area of MR dampers for gun recoil use, a gun recoil demonstrator (see Figure 10) was built. A double-ended MR damper was placed behind a single-shot, bolt-action rifle that was mounted on a ball bearing recoil slide. The caliber that was chosen for this test apparatus was the 50-caliber Browning Machine Gun (50BMG) cartridge. This cartridge was chosen because of its high recoil energy, its availability, and the armed force's familiarity with weapons of this caliber. A force transducer and a LVDT (linear variable differential transformer) were used in conjunction with a Hewlett-Packard dynamic signal analyzer to capture and record data for force and velocity.

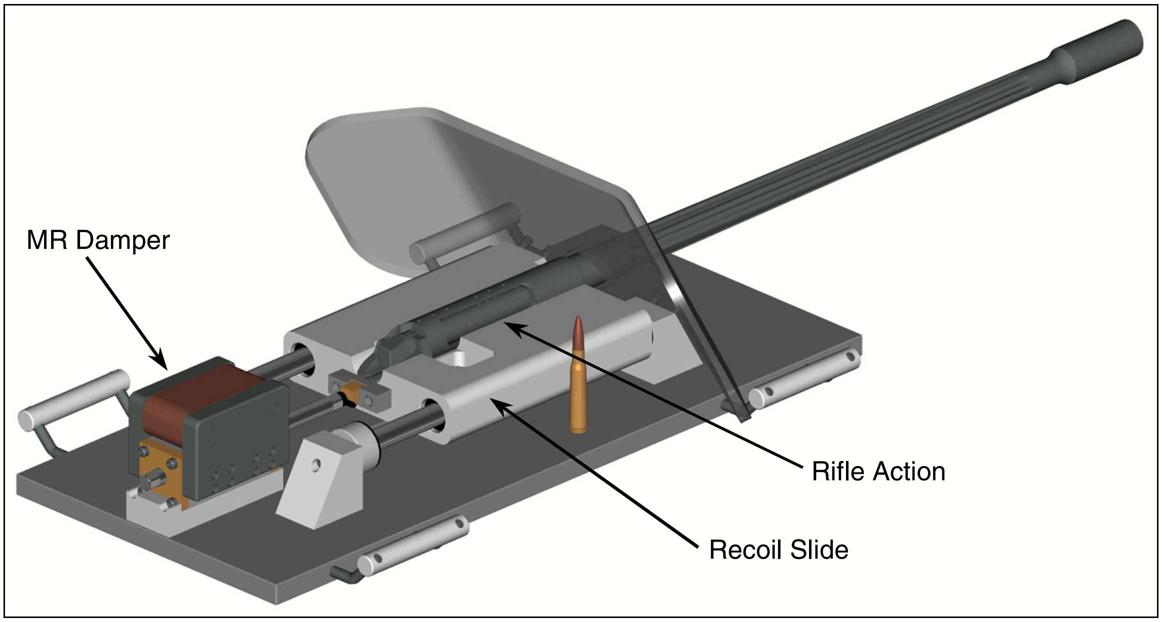

Figure 10. Gun recoil demonstrator.

To explore possibilities in the field of automotive MR dampers, a set of monotube MR dampers was designed and built for use on a Mercedes ML-430 sport-utility vehicle. A drawing of a front damper for this application was previously shown in Figure 5. To determine what force-velocity characteristics the new MR dampers would need, the original hydraulic dampers were tested in an MTS (Material Testing Systems) machine. These tests yielded force-velocity data that was then used to determine what internal geometry the new MR dampers should have. Figure 11 shows the MTS machine with a damper mounted in place. Similarly, a new, easier to manufacture version of the Mercedes ML-430 damper was built and tested.

In addition to the monotube MR dampers that were built for the Mercedes ML-430, two different MR piloted hydraulic dampers were built as well. One MR piloted hydraulic damper was built using a valve mode MR damper, and the other was built using a squeeze mode MR damper. Finally, a twin tube MR damper was built and tested. All of these automotive MR dampers were tested on the MTS machine.

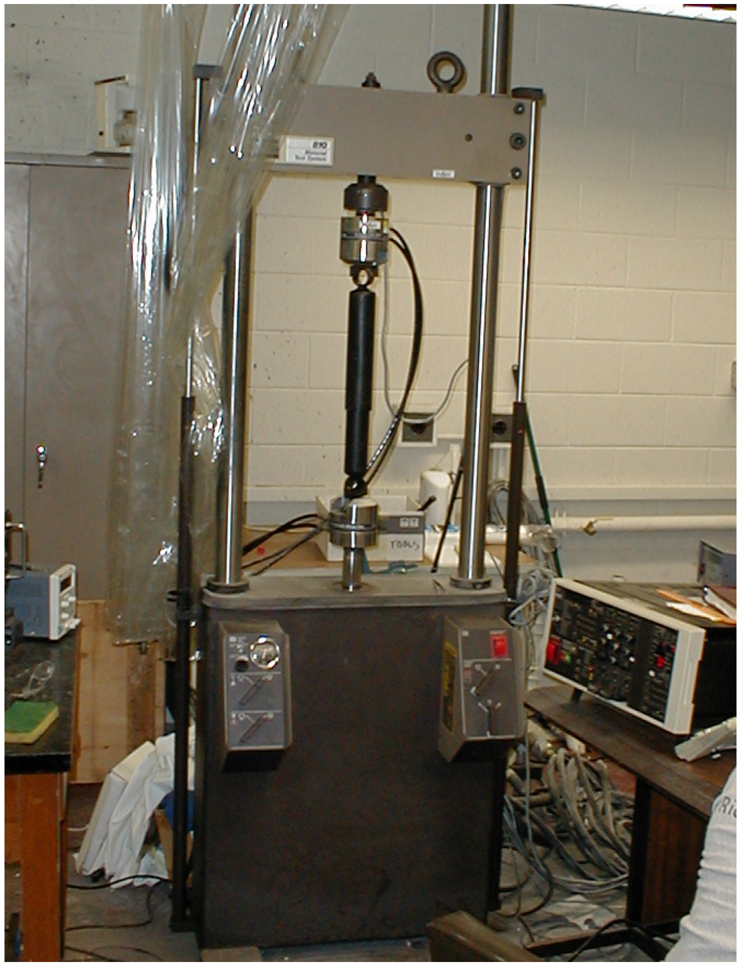

Figure 11. MTS machine used for automotive damper testing.