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Conceptual Development of Impact Overload Detection Devices for Tank Car Service

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13. ABSTRACT

The objective of this project was to develop concepts for mechanical and electronic systems that can detect yard or in-train impacts that exceed design load or other reasonable limits on tank cars. The project team developed some mechanical and electronic systems for detecting overload impacts. For the mechanical system, detection of draft gear travel and closeout offered the best chances for success. For electronic systems, this project identified the following methods for overload impact detection:

- Measuring a combination of draft gear travel and draft gear velocity
- Measuring impact force using piezo-electric film
- Using acceleration measurements for overload detection

Although the team developed a fairly accurate way to estimate overload impacts through acceleration measurements, the commercially available unit tested did not function well enough to do the same. It is possible that additional development will help the unit perform better. Therefore, it is recommended that this option not be used for electronic overload detection until additional developments are made. It might be possible for the manufacturer of the tested unit to make adjustments in its functionality that might in turn enable the unit to perform better at threshold detection and transmission.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC		METRIC TO ENGLISH	
LENGTH (APPROXIMATE)		**LENGTH** (APPROXIMATE)	
1 inch (in)	= 2.5 centimeters (cm)	1 millimeter (mm)	= 0.04 inch (in)
1 foot (ft)	= 30 centimeters (cm)	1 centimeter (cm)	= 0.4 inch (in)
1 yard (yd)	= 0.9 meter (m)	1 meter (m)	= 3.3 feet (ft)
1 mile (mi)	= 1.6 kilometers (km)	1 meter (m)	= 1.1 yards (yd)
		1 kilometer (km)	= 0.6 mile (mi)
AREA (APPROXIMATE)		**AREA** (APPROXIMATE)	
1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)	1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)	1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)	10,000 square meters (m^2)	= 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)		
MASS - WEIGHT (APPROXIMATE)		**MASS - WEIGHT** (APPROXIMATE)	
1 ounce (oz)	= 28 grams (gm)	1 gram (gm)	= 0.036 ounce (oz)
1 pound (lb)	= 0.45 kilogram (kg)	1 kilogram (kg)	= 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)	1 tonne (t)	= 1,000 kilograms (kg)
			= 1.1 short tons
VOLUME (APPROXIMATE)		**VOLUME** (APPROXIMATE)	
1 teaspoon (tsp)	= 5 milliliters (ml)	1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	= 15 milliliters (ml)	1 liter (l)	= 2.1 pints (pt)
1 fluid ounce (fl oz)	= 30 milliliters (ml)	1 liter (l)	= 1.06 quarts (qt)
1 cup (c)	= 0.24 liter (l)	1 liter (l)	= 0.26 gallon (gal)
1 pint (pt)	= 0.47 liter (l)		
1 quart (qt)	= 0.96 liter (l)		
1 gallon (gal)	= 3.8 liters (l)		
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)	1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)	1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)		**TEMPERATURE** (EXACT)	
[(x-32)(5/9)] °F	= y °C	[(9/5) y + 32] °C	= x °F

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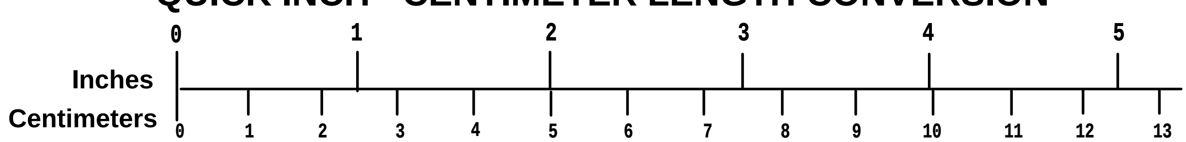

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

The objective of this project was to develop concepts for devices that detect when tank cars see overload impact forces and indicate the same to a car man or an inspector visually or through other means. This project explored the feasibility of both mechanical and electronic systems for detecting impact for feasibility. The concepts developed were to be self-contained and capable of detecting yard or in-train impacts that exceed design load or other reasonable limits. The devices were to be conceptually adaptable to a range of tank car types and draft gear combinations, be capable of long-term use without need for frequent maintenance, and be of reasonably low cost. Feasible concepts were to be extended into prototypes, and their functioning was to be tested.

The project team first identified multiple means of detecting overload. Although the most fundamental means of detecting overload impact are to measure and track coupler force, traditionally, coupler force has not lent itself to simple measurement schemes. Secondary (and indirect) means of measuring coupler overload include measurement of draft gear travel and measurement of car accelerations. These methods have their advantages and disadvantages.

Draft gear travel measurement lends itself to simpler systems (both electronic and mechanical) compared to force measurement. Given the significant variations in draft gear arrangements and performance, however, it is difficult to consistently relate coupler force to draft gear travel across draft gear models and conditions. It is feasible, however, to detect draft gear closeout events and relate them to high coupler loads. In addition, the research team has established the possibility of developing systems that evaluate coupler force as a function of draft gear travel and velocity with good reliability.

Acceleration measurements are affected by the fact that accelerations felt for a given impact load are dependent on the mass of the car. The team has established the potential for detecting overload impacts through acceleration measurements by conducting extensive impact testing. While this does not allow one to directly compare coupler forces to accelerations at low and medium impacts, overload events can be clearly identified.

The project team has developed some mechanical and electronic systems for detecting overload impacts. For the mechanical system, detection of draft gear travel and closeout offered the best chances for success. As far as electronic systems go, this project identified the following methods for overload impact detection:

- Measuring a combination of draft gear travel and draft gear velocity
- Measuring impact force using piezo-electric film
- Using acceleration measurements for overload detection

The mechanical system developed measures draft gear travel at each impact, tracks the highest travel level experienced, and communicates it through a dial and pointer system. Essentially, the system is mounted on the bottom flange of a tank car stub sill and measures movement of the follower block with respect to the stub sill. The system also tracks the number of impacts that exceed a certain threshold. The system was tested and performed reliably in both laboratory and field conditions. The research team observed that the mechanical system provides a simple, robust, low-cost, low-maintenance system for tracking tank car overload impacts.

A method to measure draft gear travel and velocity electronically was developed. The system uses a rotating magnetic field to generate an electric potential in a coil of wire (similar to a generator). The output of this coil may be directly related to the coupler force. The concept was developed into a prototype and tested in laboratory settings, where it functioned reliably. Additional work is needed, however, before any field testing of the system can begin.

The prospect of using piezo-film as a way to detect overload impacts was tested using a standard drop hammer test setup. The advantage of a piezo-film is that it requires no excitation voltage. Upon quickly applied pressure, it outputs a voltage or charge. Two different configurations for using the piezo-film were tested. The tests indicate that piezo-film measurements have a good chance of success. Further testing and development, however, are needed.

For acceleration-based overload detection, a commercially available unit was tested. The unit generates and transmits a report via satellite to a secure Web page whenever a certain acceleration level is exceeded. The report includes the level of acceleration exceeded, the speed of the impact (from integration of the acceleration), and the location of the impact via Global Positioning System (GPS) software/satellite. During the tests the team used other accelerometers to evaluate the accuracy of the subject remote data analyzer and transmitter. While the unit tested functioned satisfactorily in some cases, it did not perform reliably in many cases. Although the project team did develop a fairly accurate way to estimate impact force via accelerations, the unit that was tested did not function well enough to do the same.

1. Introduction

1.1 Background

During the course of normal rail transportation activities, tank cars and other freight cars are frequently subjected to high impact forces during hump yard activities. The magnitude of these forces depends on the masses of impacting cars/consists, impact speeds, and draft gears. Tank cars use draft gear systems that are designed to absorb a portion of the energy from the impacts, thereby softening the blow to the cars themselves. Many draft gear systems, however, are often overwhelmed by impact forces at higher speeds; they use up all the available travel and go solid. When a draft gear goes solid, it cannot absorb any additional energy, and impact forces are transmitted directly to the car structure. During a series of impact tests conducted on a 263,000-lb tank car, it was found that some draft gears can go solid at speeds as low as 4 mph. At higher speeds, impact forces increased significantly. Forces as high as 750,000 lbs were observed at speeds of 6 mph. Million pound coupler forces may be observed at speeds as low as 7 mph. Such high forces can accelerate crack propagation from pre-existing defects, leading to cracks in the tank shell or even stub sill separation. Cracks in the tank shell lead to loss of lading, which is dangerous if the car is transporting hazardous materials, presenting the risk of physical harm or bodily injury to rail workers and the public. Stub sill separation can result in lading loss and even derailment. Numerous incidences of tank shell fracture have been observed in the United States and Canada, where the failure was impact induced. With tank cars starting to be used in 286,000-lb service, the number of such incidences is likely to grow.

Many such failures can be avoided by more careful inspection of the stub sill-tank head area. This would help detect cracks while they are still small, thereby avoiding more serious problems. Frequent and detailed inspections of all tank cars, however, are infeasible due to time and cost constraints. Often tank cars are covered with insulation and jackets that prevent easy inspections of the tank shell. An alternate option is to conduct detailed inspections of those cars that have seen high impact loads. For this to work, one needs an overload impact detector device that would indicate whether the car was subjected to a high impact load. Such a device would provide a clear indication that the structural rigidity of the car may have been compromised and that an inspection is necessary to ascertain that any existing small cracks have not grown to a critical stage. The objective of this project is the conceptual development of such a device.

With more detailed inspections of cars that have been subjected to high impacts, incidents like tank shell fracture, lading loss, sill separation, and derailment can be minimized, thereby improving operational safety. An overload impact detector will go a long way towards identifying the cars that need such detailed inspections and focusing limited resources towards cars that need the most attention.

1.2 Objective

The objective of this project is to develop concepts for devices that detect if tank cars have seen overload impact forces and indicate the same to a car man or an inspector visually or through other means. This project will explore the feasibility of both mechanical and electronic systems for detecting impact. The detector should be a relatively low-cost device that is self-contained and capable of detecting yard or in-train impacts that exceed design load or other reasonable limits. The device should be conceptually adaptable to a range of tank car types and draft gear combinations and be capable of long-term use without need for frequent maintenance. Feasible concepts are to be extended into prototypes, and their functioning is to be tested in laboratory and field settings.

2. Concept Development

The most fundamental means of detecting overload impact would be to measure and track coupler force. Traditionally, however, coupler force has not lent itself to simple measurement schemes. Mechanical means of measuring coupler force would generally involve altering either the force path or changing draft gear characteristics; both of which would be undesirable. Electronic schemes have generally involved significant strain gaging, signal processing, and data acquisition, which do not lend themselves to simple low-power, cost-effective applications.

Secondary (and indirect) means of measuring coupler overload include measurement of draft gear travel and measurement of car accelerations. Both of these methods have their advantages and disadvantages.

2.1 Measurement of Draft Gear Travel

Draft gear travel measurement lends itself to simpler systems (both electronically and mechanically) compared to force measurement. Given the significant variations in draft gear arrangements (steel, rubber, polymer, and combinations thereof, with multiple friction wedge designs) and performance, however, it is difficult to consistently relate coupler force to draft gear travel across draft gear models and conditions. In most cases, however, a significant possibility of an overload impact exists if the draft gear has closed out or is close to closing out. By detecting the incidences of this event, one could detect potential overloads. In addition, if draft gear travel were to be measured electronically, one could also calculate draft gear closure speeds from the measured travel. This could be combined with travel data to better detect overload conditions.

To better establish the theoretical feasibility of using draft gear closure velocities in combination with draft gear travel, the research team studied existing test data on draft gear travel and velocity (differentiated from the draft gear travel time histories). This analysis revealed that a distinct potential existed for representing coupler force as a function of draft gear travel and velocity with good reliability.

2.2 Measurement of Acceleration

Acceleration measurements are affected by the fact that accelerations felt for a given impact load are dependent on the mass of the car. In other words, a loaded car and an unloaded car would generate different acceleration responses to a given impact load. Given that the device will reside on the car at all times and must be self-contained, evaluating actual impact load based on acceleration measurement is not practical. In addition, accelerometers in general are not low-power devices, making long-term monitoring a challenge.

The team explored the feasibility of relating coupler loads to peak accelerations by studying acceleration data measured during tank car impact tests. These tests were conducted with two different draft gear models under three different car loading conditions: fully loaded, half-loaded, and empty. The researchers also conducted these tests with the tank car backed up by two other cars and with the tank car free-to-roll (no backup cars). Analysis of measured data revealed that no significant differences existed in acceleration between the free-to-roll condition and the backup cars condition (see Figure 1). The team observed significant differences, depending on the loading condition, implying that one could not independently determine coupler force based on acceleration measurements alone. Figure 2 shows acceleration measurements plotted against coupler force for three different tank car load levels. At lower force levels, a separation exists between the three loading levels, with the empty case producing the highest accelerations and the loaded case producing the lowest. At higher coupler forces (>750,000 lbs), however, the dependence on car load levels is reduced. For example, by setting an acceleration threshold of 7 g, one could potentially detect most overload events. The number that is picked for such a threshold (7 g in this case) will depend significantly on the sample rates and filters used on an accelerometer, and these will have to be specifically designed for a given system of acceleration sensors. Occasionally high impact forces may not be associated with high accelerations. Figure 2 shows the instances where forces over 700,000 lbs produced peak accelerations under 6 g for the empty case.

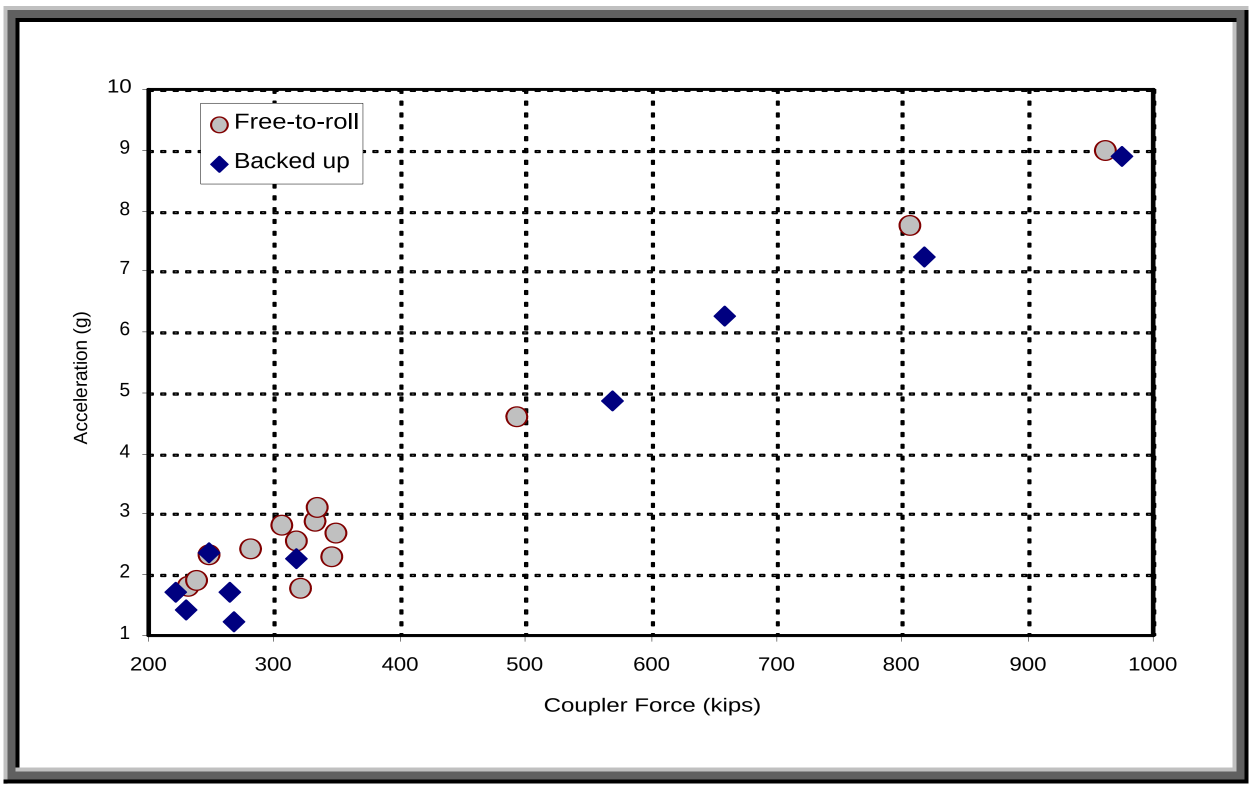

Figure 1. Comparison of accelerations–Free-to-roll versus backed up

Figure 3 shows the relative independence of draft gear type on carbody accelerations at higher force levels. Under high force levels, model 1 and model 2 produced similar accelerations. The above analyses indicate that the potential exists for using acceleration measurements to detect overload. The reliability of those systems for detecting overloads, however, will be less than perfect.

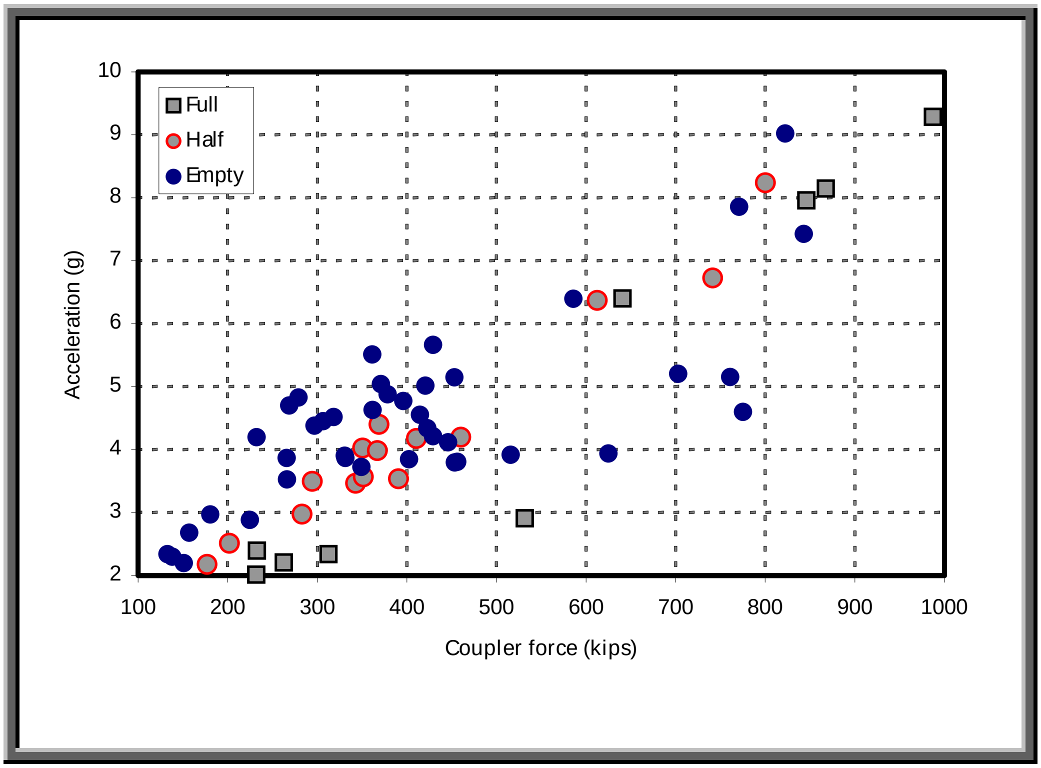

Figure 2. Comparison of accelerations–Level of loading

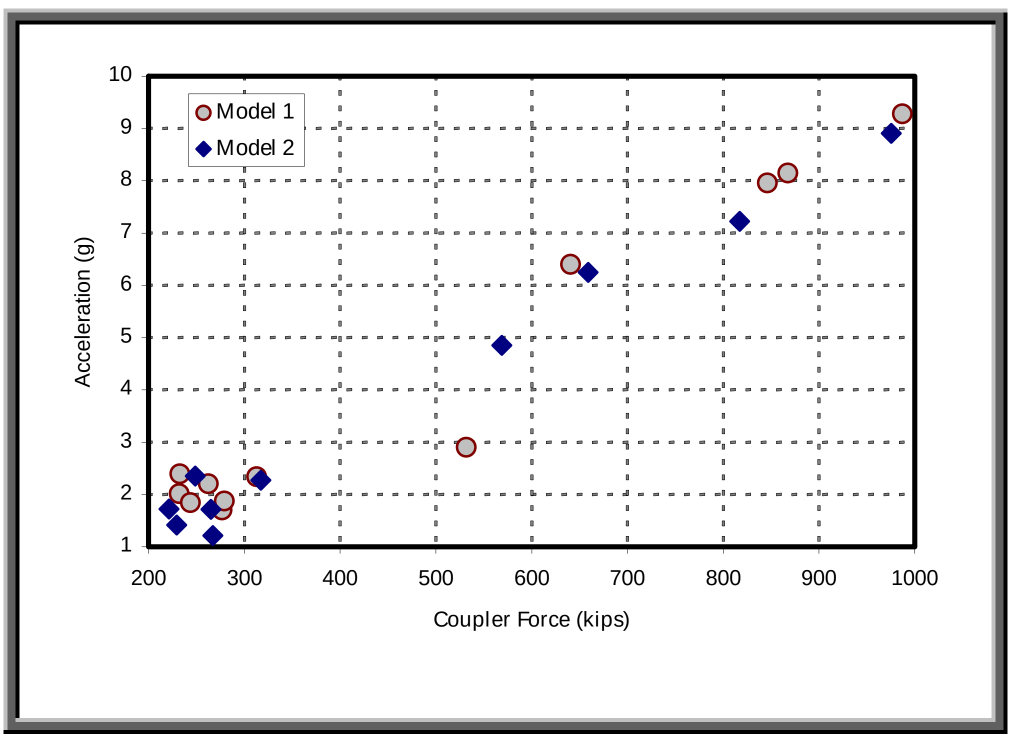

Figure 3. Comparison of accelerations–Draft gear type

2.3 System Development

After scoping out potential methods for detecting overload impacts, the team broadly identified some mechanical and electronic systems for detecting overload impacts. For the mechanical system, detecting of draft gear travel and closeout seemed to offer the best chances for success. Chapter 3 describes the development effort for this system. As far as electronic systems go, the project identified the potential for measuring draft gear travel in conjunction with closure speed for overload detection. Chapter 4 outlines this system. The team has also identified the possibility of using piezo-electric film for load measurement. Chapter 5 describes the work on this concept. Chapter 6 discusses the work with using acceleration measurements for overload detection.

2.4 Test Bed

Given the extent of prototype and design work that would be needed in this project, the research team decided to set up a test bed for evaluating various concepts. Essentially, this test bed would have to simulate the sill structure of a tank car, including the draft gear, yoke, and coupler. It had to permit the mounting of various test systems on it to determine functionality. The test bed also had to serve as an apparatus for demonstration of concepts. Based on the requirements of the system, specifications were laid out, and a design was developed. The team then fabricated and assembled the various components of the test bed. The components included standard coupler and yoke assemblies. Mockups of the draft sill and draft gears were created for this assembly. The fabricated sill included provision of the front and rear draft lugs and cutaways to permit easy diagnosis of potential problems during concept development. Figures 4 through 6 show three different views of the test bed. In the pictures, the sill is painted brown, the draft stops are painted yellow, the follower block is orange, the yoke is blue, the draft gear is green, and the coupler is painted gray.

Figure 4. Test bed

Figure 5. Test bed–View from top

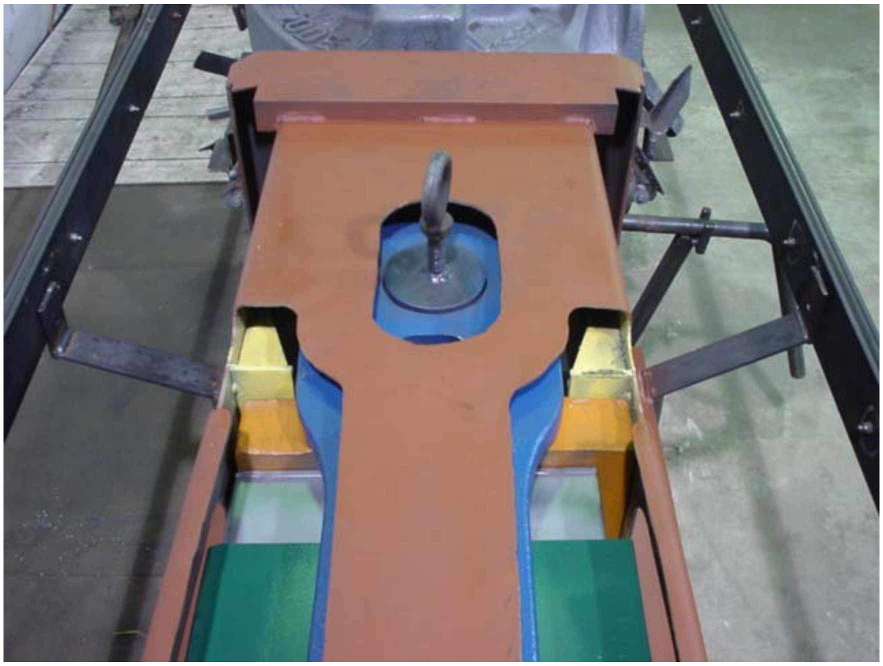

Figure 6. Test bed–View of draft stops and follower

3. Mechanical System

The mechanical system developed measures draft gear travel at each impact and keeps track of the highest travel level experienced. The maximum travel seen is communicated through a dial and pointer system. Essentially, the system is mounted on the bottom flange of a tank car stub sill and measures movement of the follower block with respect to the stub sill. The follower block tracks draft gear travel directly and in real time; hence a measurement of follower movement is a direct measurement of draft gear travel.

On a typical tank car, while draft gear travel is predominantly longitudinal, some small lateral and vertical motions exist. While movements in the lateral and vertical directions are small, significant forces may be associated with them. Therefore, a system that measures draft gear travel needs to be unaffected by these movements and resulting forces. To achieve this, the project team designed a system by which linear longitudinal motion of the follower was translated to rotary motion through the use miter gears. In addition, the link between the system and the follower had slots built in that isolated the system from lateral and vertical movements of the follower. The rotary movement was translated to a pointer on a dial that indicated the maximum travel. Record of maximum travel was maintained by using a simple ratchet mechanism. The device was designed to be reset by the press of a button. Figure 7 shows a cross-section of the mechanical system.

After conceptual design of the system, the team developed detailed drawings for fabrication and assembly. Once assembled, the device was installed on the test bed to verify functionality. Some of the improvements and refinements needed were identified and incorporated. The researchers also pursued the possibility of tracking the number of overload impacts, in addition to the peak overload, at this stage. Accordingly, a mechanical counter to keep track of the number of impacts that exceed a certain threshold was designed. This design was subsequently fabricated and added to the mechanical system. The design is set up such that the threshold for an event count can be modified by the car owner to suit the owner's criteria.

Subsequent to these revisions, the team conducted additional tests of the mechanical system on the test bed. These indicated that the concept generally works as intended. To verify the system's durability and operation in actual field conditions, it was installed on an actual tank car and subjected to impact testing. Figures 8 and 9 show the system installed on the bottom flange of the tank car. The system was subjected to multiple series of impacts raging from 1 mph to 8 mph (and forces from 200,000 lbs to nearly 1,000,000 lbs) and worked well. Both the maximum travel tracking mechanism and counter worked well. During the tests, the researchers identified some minor modifications that could be made to the system to improve performance. These included more robust connections for the counter mechanism that counts the number of overload impacts. Figures 10 through 13 show additional views of the system as it was installed on the test tank car.

In conclusion, it was seen that the mechanical system would provide a simple, robust, low-cost, low-maintenance system for tracking tank car overload impacts. The system has been designed such that it can be easily retrofitted to most existing tank cars with little or no modification. While some doubts exist about how well draft gear travel represents coupler force, it has been established that over-solid impacts generally result in high coupler forces. The system designed should be able to detect and track such impacts. The system can also be further improved to include dials on both sides of the car to allow for easier inspection. Some additional work is needed to make the counter robust. The system must be made weatherproof for better foul weather performance.

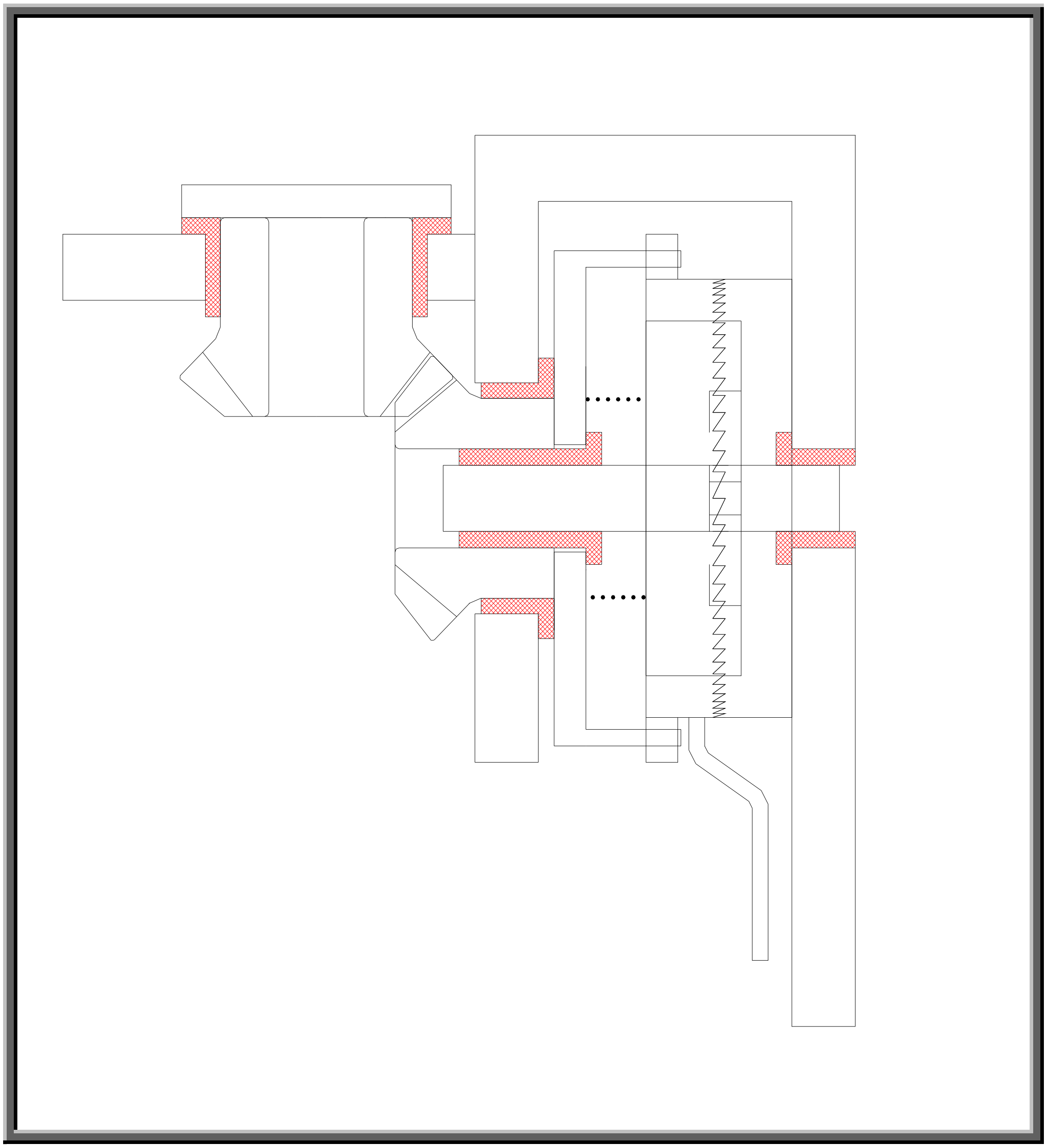

Figure 7. Cross-section of mechanical overload detection system

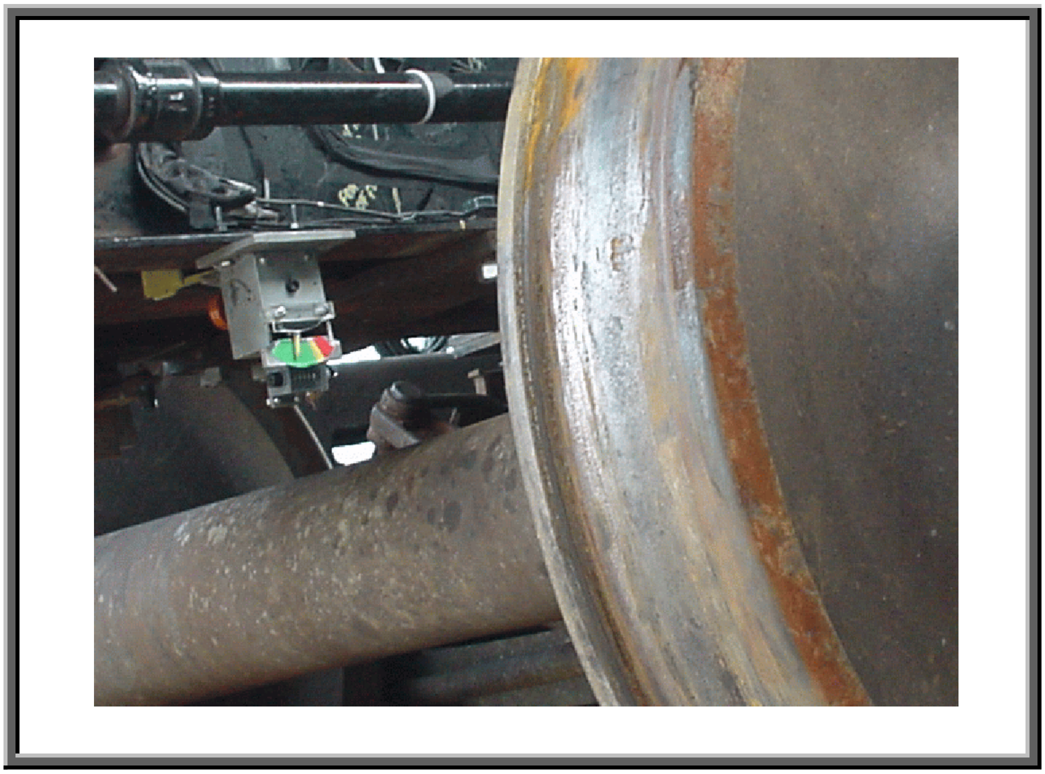

Figure 8. Mechanical system installed on test tank car

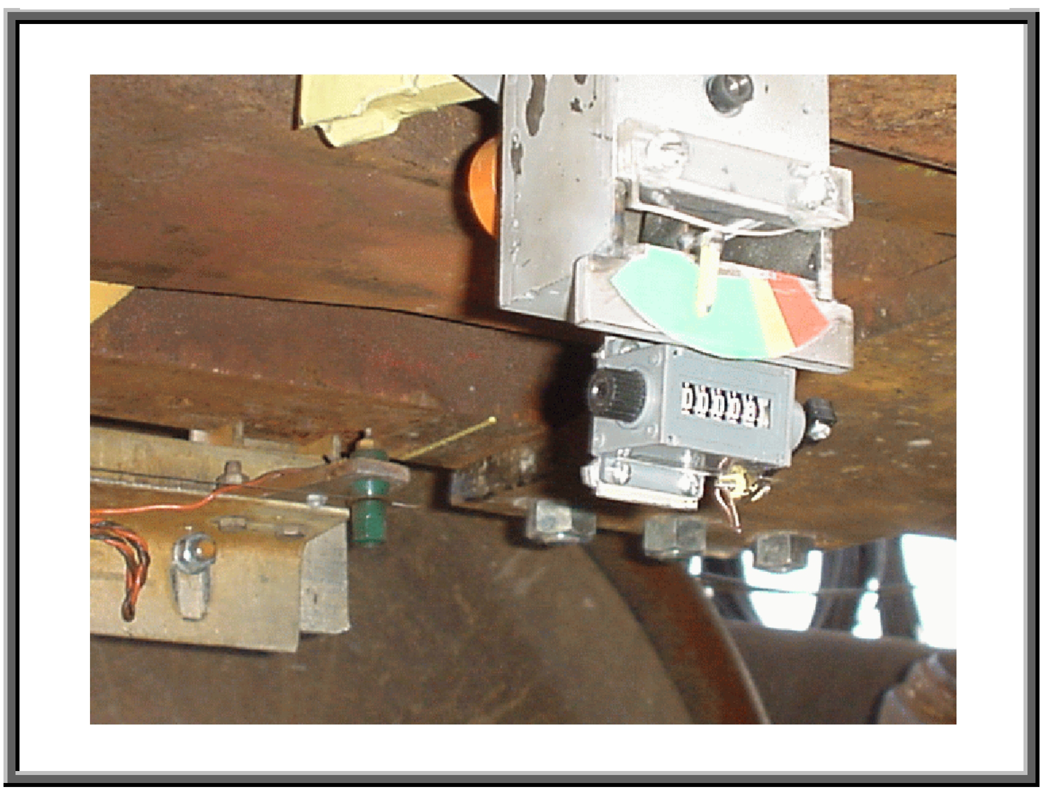

Figure 9. View of mechanical counter

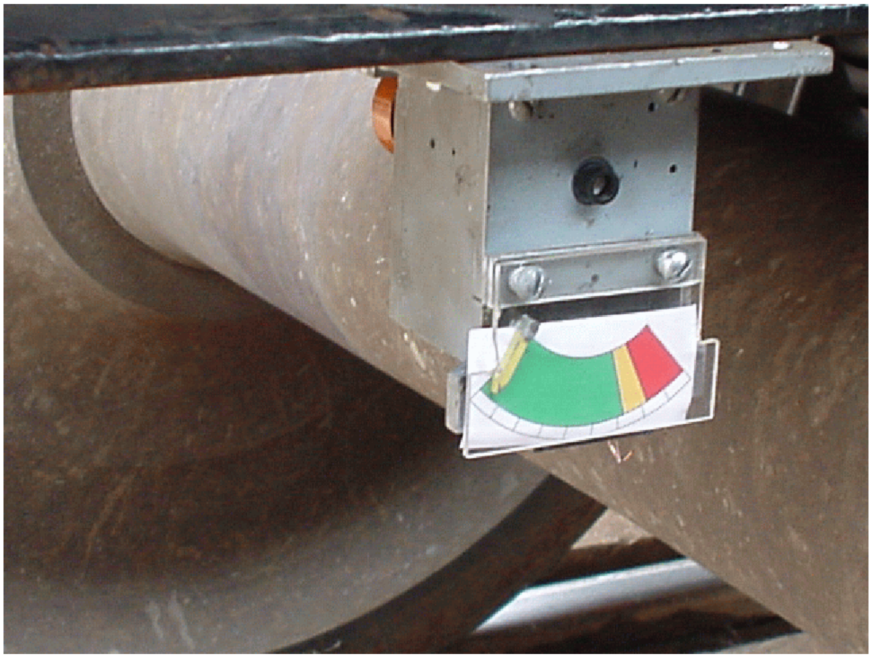

Figure 10. Mechanical system–After a low-speed impact

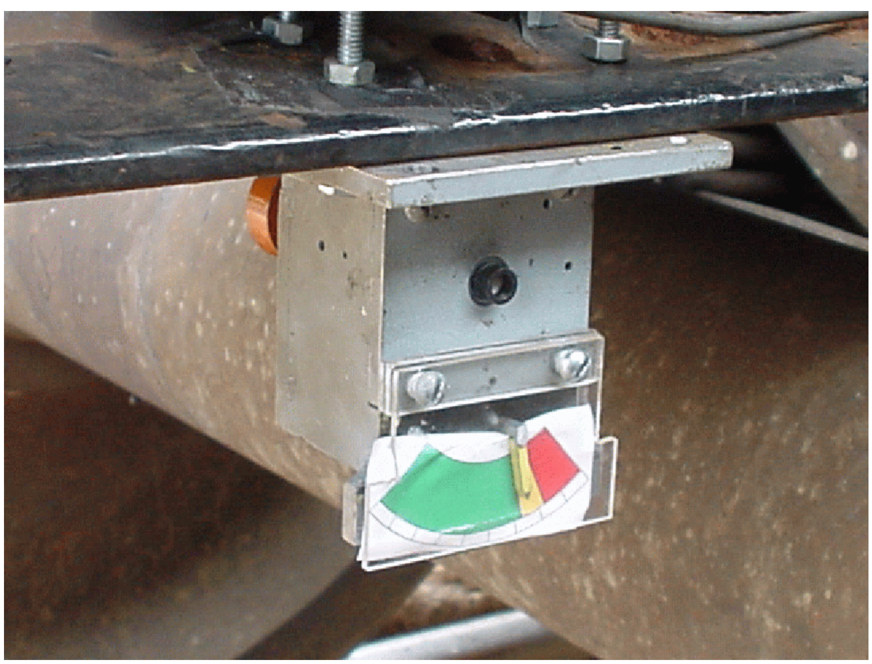

Figure 11. Mechanical system–After a medium-speed impact

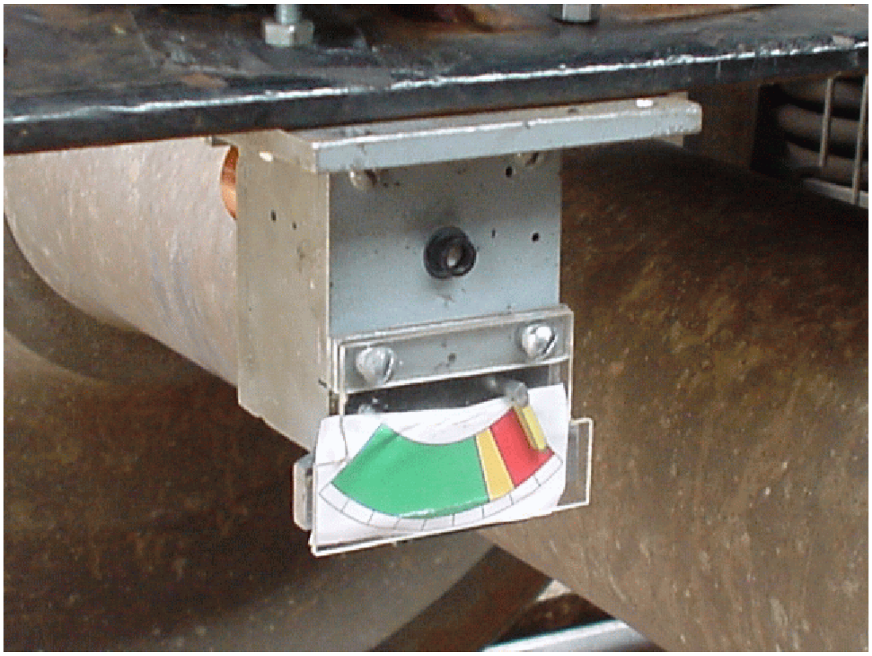

Figure 12. Mechanical system–After a high-speed impact

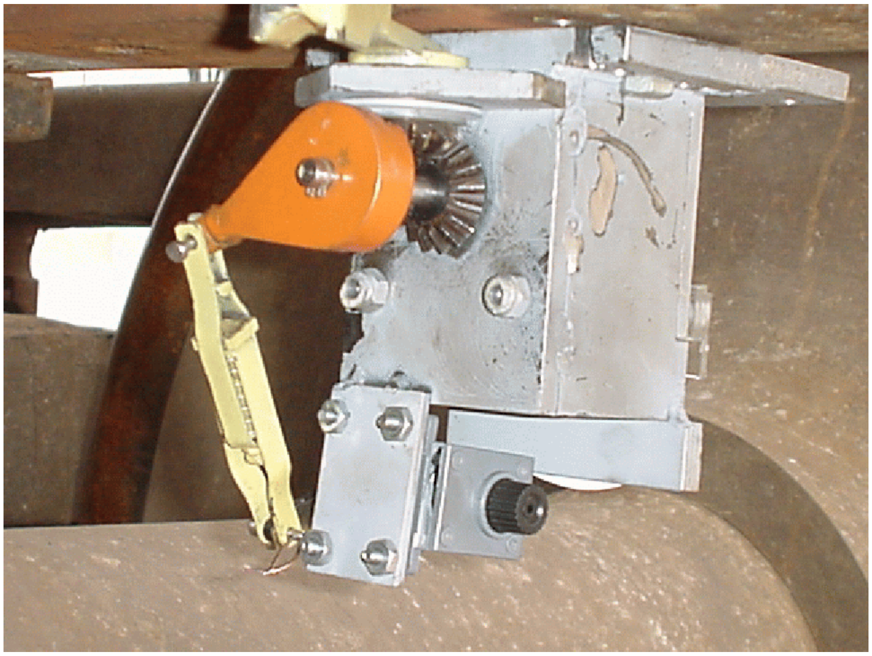

Figure 13. Rear view of mechanical system

4. Measuring Draft Gear Travel and Velocity–Electronic System

In the case of all electronic overload detection systems, it is essential to keep the power consumption of the system down since the systems will be expected to work for long durations without any human intervention. Additionally, most of the systems will have some memory, logic, and data acquisition requirements to be able to detect and analyze events with respect to preset thresholds and activate alarms as needed. Such tasks are best accomplished through the use of a microcontroller with low-power requirements. As a first step, the research team identified some microcontrollers with low-power requirements that would be capable of these tasks. These controllers can be combined with analog-to-digital converter chips and suitable sensors to make an impact detection system.

Analysis of test data on draft gear travel and corresponding velocities has indicated that travel levels used in conjunction with velocities can provide a good measure of overload coupler forces. The team has considered many methods of doing this electronically. These include the use of photo-cells, photo diodes, or hall-effect sensors to measure draft gear movement followed by computation of velocity using a microcontroller. Another scheme to combine the two measurements into a single device uses a rotating magnetic field to generate an electric potential in a coil of wire (similar to a generator). As per Lenz's law, the magnitude of the output generated would depend on both magnitude and speed of travel. Therefore, it is possible to directly relate the output of the coil to the coupler force. In addition, the sensor (the magnet-coil system) is self-powered, unlike other methods of measuring displacement. This would help significantly in reducing the power requirements of an electronic system.

The magnetic coil concept was developed into a prototype for testing on the test bed. In essence, the linear motion of the follower is translated into rotary motion of a permanent magnet, in a fashion similar to the one developed for the mechanical system. By adopting that design, many of the advantages of the mechanical system, such as the isolation of vertical and lateral follower movement, were automatically incorporated into the new system. The magnet is surrounded by an electric coil, which generates an analog output that is proportional to draft gear movement and velocity. This output is rectified, filtered, and scaled using the appropriate electronic circuitry and sent to a data acquisition chip, which then sends the measured digital data to a microcontroller (Figure 14). The microcontroller then processes the incoming data to detect peaks. For the initial tests, peak data from the microcontroller was communicated to a personal computer through a serial port. For the actual application, exceedance data will be sent to an appropriate display residing on the tank car.

The team installed the prototype system on the test bed and evaluated its functionality. Figures 15 through 18 show different views of the unit installed on the test bed, including a closeup view of the controller board. Initial tests have indicated that the system functions reliably in the lab setting. Additional work is needed, however, before any field testing of the system can begin.

Additional work to be done on the system includes the development of calibration charts that relate the output of the sensors to actual coupler forces. A display method to communicate exceedances must be developed. Suitable power sources for the system must be defined. The electronic components in the system need to be packaged to survive in the railroad environment.

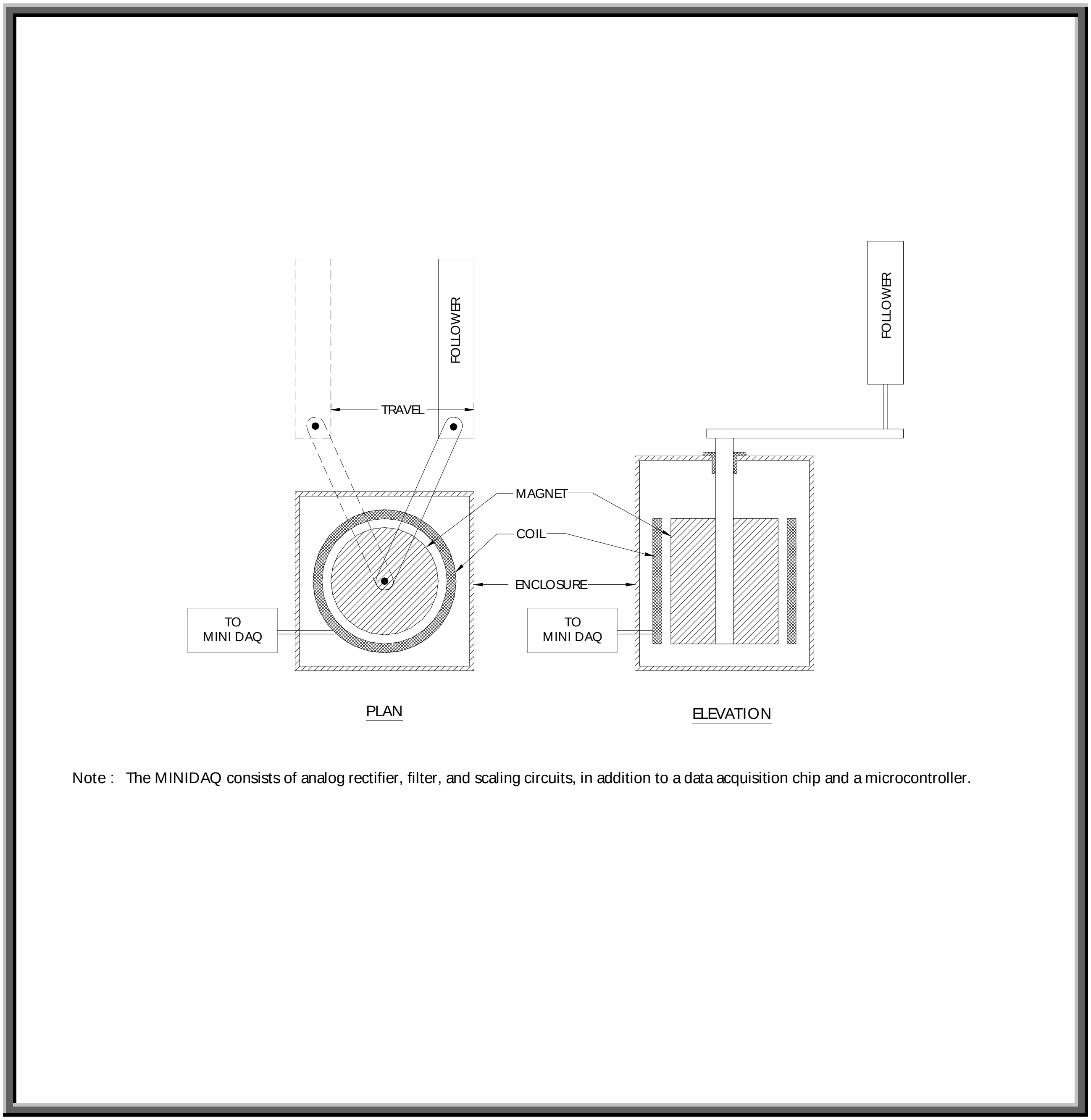

Figure 14. Schematic of electronic system for detecting overloads using electric coils

Figure 15. Electric coil system installed on the test bed

Figure 16. Closeup of electric coil system installed on the test bed

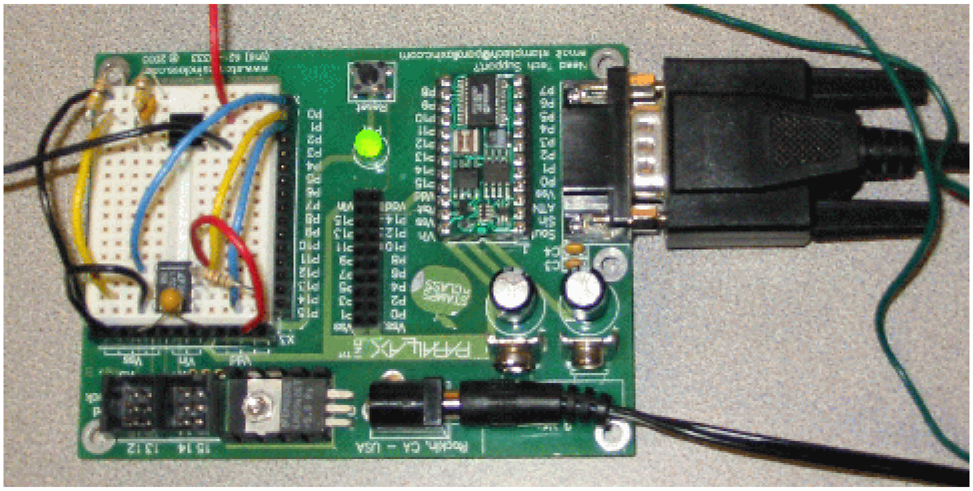

Figure 17. Microcontroller used with the electric coil system

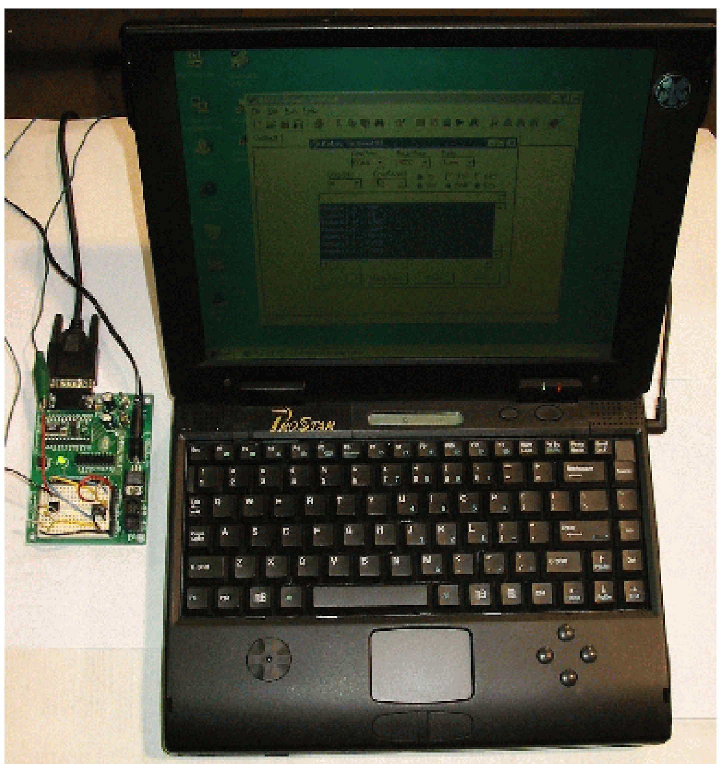

Figure 18. Laptop computer and microcontroller used for testing

Potentially, this system could also include a GPS receiver and a means of remote communication so that any exceedances can be transmitted to a central location.

In summary, the project team has established the feasibility of using such a system for impact monitoring. Additional work, however, must be done before the team begins field testing.

5. Impact Overload Detection–Piezo-Film

For quantifying forces generated from impacts and train handling with stresses on the end sill of tank cars, one would ideally choose to collect coupler force. As previously discussed, acceleration and displacement measurements are indirect methods for impact detection and not as accurate as force measurement. The problem with measuring force is that the transducer needs to be powered and does not lend itself to easy installation onto an end of a railroad car. In addition, in the case of a conventional load-cell, problems are associated with clearance in the draft pocket.

The team investigated the possibility of using piezo-film as a coupler force transducer. The advantage of piezo-film is that it requires no excitation voltage (i.e., it does not need to be powered). The film generates a voltage/charge in response to an applied pressure. Generally, the voltage generated is dependent on both the magnitude and speed of pressure application; faster applications of pressure yield higher voltage output. The pressure can be measured with the film via direct normal contact or bending of the film.

The research team has attempted to calibrate piezo-film output to impact forces through a series of drop hammer tests. Once calibrated, the number of impacts exceeding a certain force threshold (and consequently a voltage threshold) can be counted using a simple counter circuit that counts the number of times a certain voltage has been exceeded.

5.1 Film Layout and Hammer Tests

The testing was conducted under an Association of American Railroads' certified 27,000-lb draft gear drop hammer. The setup uses a typical draft gear, follower, and coupler arrangement, and it utilized a frame to guide and support the draft gear. The team tested two different piezo-film setups. For the first setup, a 5" X 8" piece of piezo-film was installed between the follower and the coupler shank, with a 1/2" thick hardened steel pad protecting the film. In this setup, the film is directly in the coupler force load path. Figure 19 is a schematic of the setup. The hammer when dropped struck the coupler first. Figures 20 and 21 are photographs of the first test setup.

During the initial hammer drops (coupler forces up to 600,000 lbs), the film generated a good response. At higher drops, however, the slightly rough surfaces of the follower block started wearing into the film, causing cracks to form in the film. Once the film begins to crack, the voltage output drops off. Overall, the test indicated a distinct potential for using the film in this setup for overload impact monitoring, provided that the film is protected better. Additional film protection can be easily provided by using a thicker protective pad and smoother surfaces on the follower and the pad.

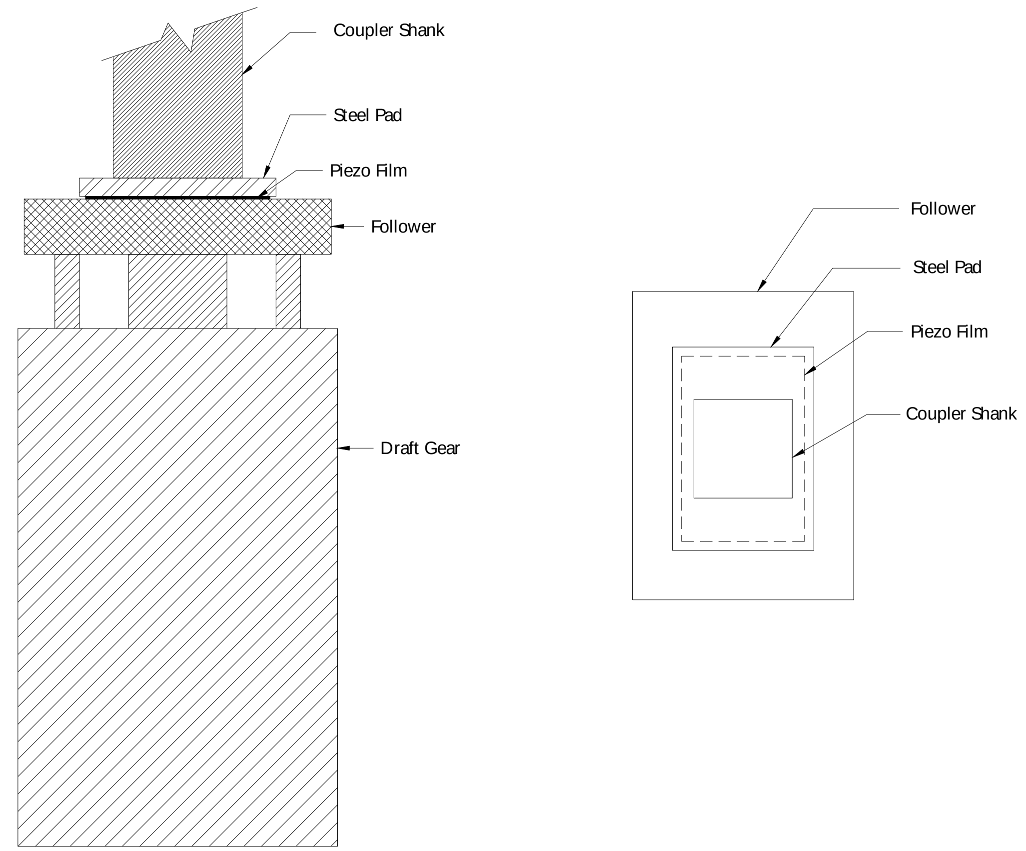

Figure 19. Schematic of piezo-film concept–Setup 1

Figure 20. 27,000-lb hammer over test setup

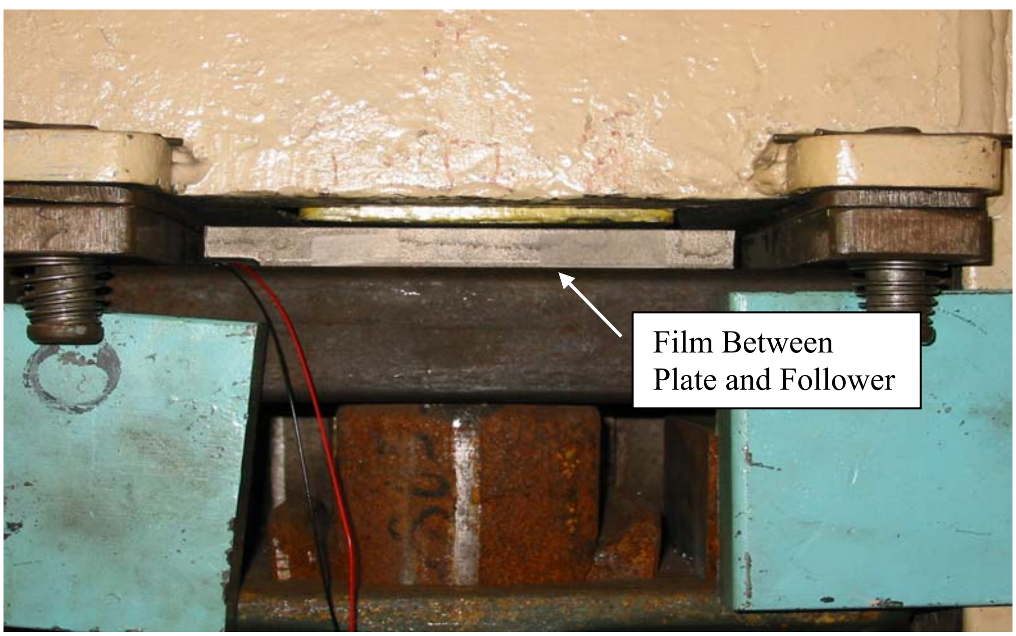

Figure 21. First test installation setup with 5" x 8" piezo-film

For the second setup, a ½" x 2 ½" piece of piezo-film was installed onto a non-contact area of the follower surface (i.e., not in the direct line of action of the coupler force). Figure 22 shows the location of where this film was placed in the test setup. Figure 23 shows a schematic. The way in which this film was installed produces a voltage due to bending of the follower resulting from impact force. This setup proved much better in being able to calibrate the voltage output of the film to the input coupler force. In addition, the team was able to drop the hammer to over-solid height of the draft gear (over 1,000,000 lbs). In other words, the setup functioned well under a simulated over-speed impact (albeit with a hammer). This application holds promise for the next step of development, which should include field testing on a ramp-track (real car-to-car impact testing).

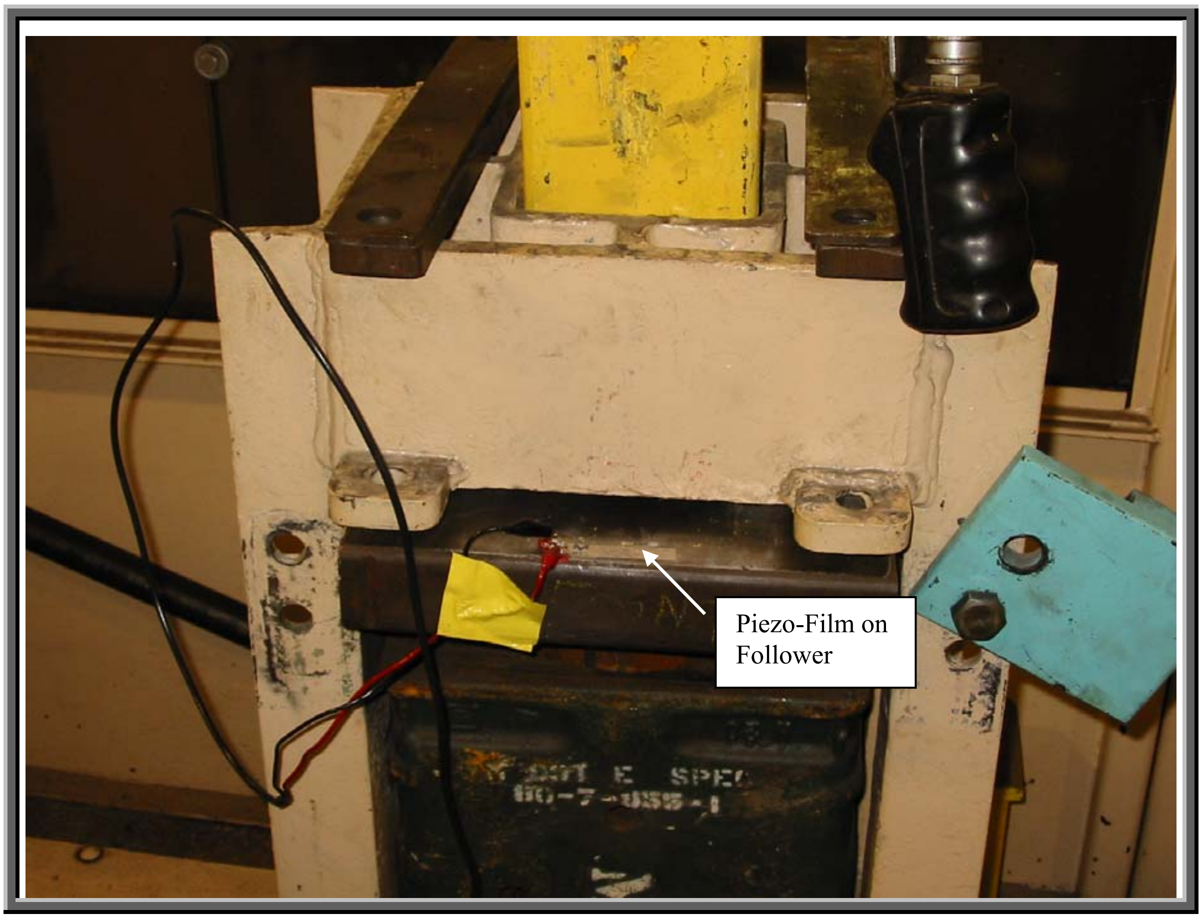

Figure 22. Test setup number 2

For both setups, the hammer was dropped from heights of 0.25" to 14.5" in increments of mostly 0.5" in order to define the voltage-coupler force calibration curve. The project team could only get up to 13" of drop height with the 5" x 8" film due to the cracking of the film.

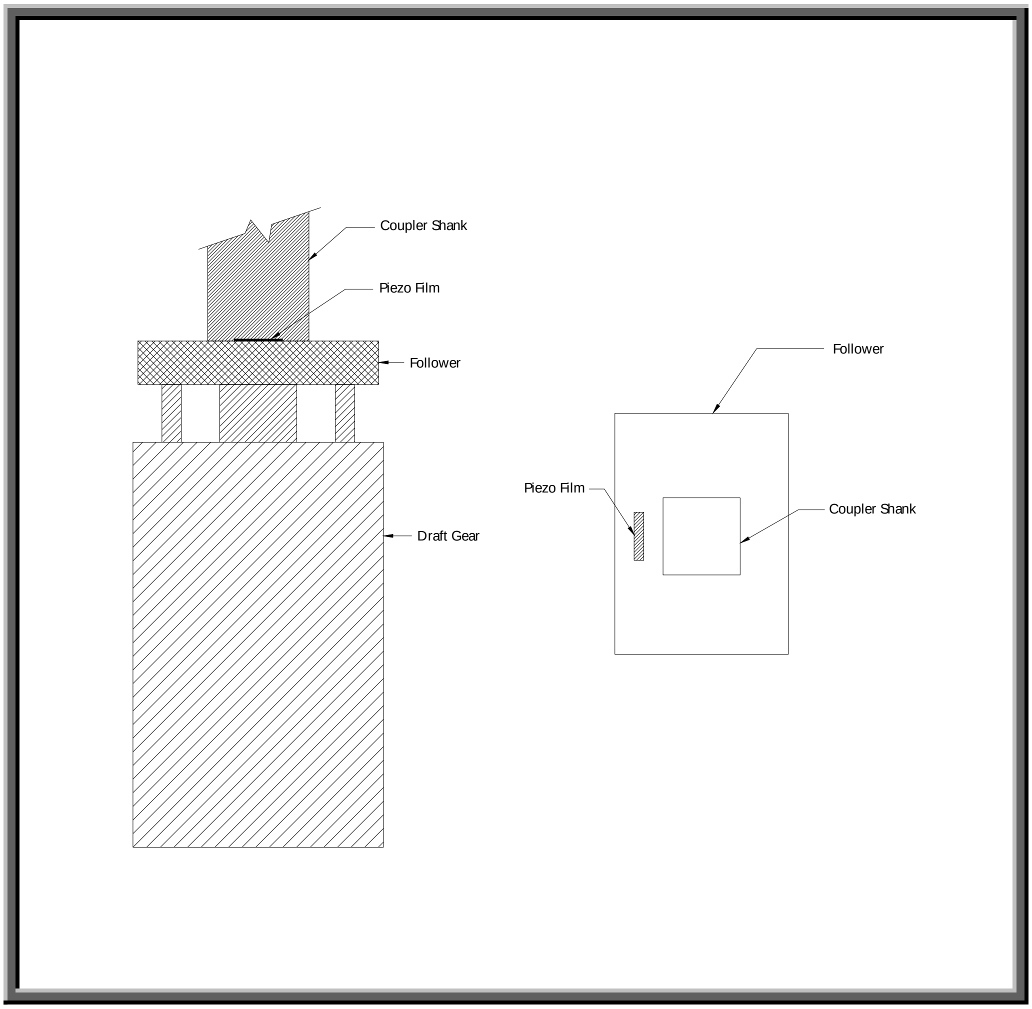

Figure 23. Schematic of piezo-film concept–Setup 2

5.2 Recommendations

The prospect of using piezo-film and an electronic counter as a device to notify a car owner of high-speed impact (>4 mph) is fairly good. Additional development work, however, is needed to make the device effective and usable. The following outlines the tasks that need to be accomplished in this development process:

- Conduct a series of car-to-car impacts (on an impact ramp) to calibrate the piezo-film output with impact forces. This is because impact speeds in car-to-car scenarios are generally lower than impact speeds seen in drop hammer tests. This is important because the output of the piezo-film depends significantly on the rate of pressure change. This exercise must be done before developing a counter circuit and display, as the voltage threshold is not known. Simultaneously, during impact testing, vary the temperature of the film as much as possible to check for direct current drift and response changes.
- Develop a counter circuit that would increment upon input of a certain voltage level as output from the piezo-film due to impacts.
- Conduct another series of car-to-car impacts to check out the piezo-film, counter circuit, and display.
- Develop a field service system that is more robust and weatherproof, and make any necessary improvements learned from previous testing.
- Install the system on a single or multiple cars for over-the-road reliability testing.

6. Acceleration-Level Detection with GPS

6.1 Testing and Results

For acceleration-based overload detection, the research team tested a commercially available remote data analyzer and transmitter. This particular analyzer uses a triaxial accelerometer for acceleration-level detection. When a preset acceleration threshold is exceeded, a report is generated and transmitted via a cellular network to a secure Web page. The report includes acceleration exceedance information, a calculated impact speed (integration of the acceleration), and car location via GPS.

The researcher installed the unit on a test tank car in a manner recommended by the manufacturer. The tank car was then subjected to a series of impacts on an impact ramp using a hopper car loaded to 263,000 lbs as the hammer car. The intent of the testing was to evaluate the effectiveness of using acceleration-based units for overload detection, by calibrating the acceleration measurements with the impact forces during car-to-car impact testing. During the tests, other accelerometers were used to measure the accelerations due to the impacts and as a check of the accuracy of the subject remote data analyzer and transmitter.

The unit tested did not perform reliably in most cases. On multiple occasions, the exceedances were not transmitted. Even when they were transmitted, accelerations and speed were often misreported.

6.2 Conclusions and Recommendations

Although the team developed a fairly accurate way to estimate overload impacts through acceleration measurements (see Section 2.2), the commercially available unit tested did not function well enough to do the same. It is possible that additional development, especially with regard to data processing algorithms, will help the unit perform better. Therefore, it is recommended that this option not be used for electronic overload detection until additional developments are made. It might be possible for the manufacturer of the tested unit to make adjustments in its functionality that might in turn enable the unit to perform better at threshold detection and transmission. The research team used an off-the-shelf model for these tests because it is presently being used in the industry for various types of incident notification.