Engineering a Superior Bumper Reinforcement System with a Piezoelectric Force Sensor in High Energy Collisions

Introduction

The inspiration of this project came from sitting in a driver's education class and hearing about what type of bumpers are on cars. The instructor explained bumpers on cars from 1973 to 1982 are actually safer than current bumpers, because of the "5 mph bumper law" which was repealed in 1982. The 5 mph bumper law mandated that a front and back bumper could withstand an impact at 5 mph, without damage. The inspiration for this project was that if someone were to develop a better bumper that could withstand more than a 5 mph, perhaps cars could be made to be safer no matter what speed they are travelling. Seventy five percent of fatal urban crashes happen below 48 kilometers per hour (2). Clearly, at any speed cars can be dangerous. Traffic injuries are calculated to be the second non-intentional cause of death. On average 1.25 million people die each year from vehicle related accidents (1). An additional twenty to fifty million people are injured or disabled each year in vehicle accidents throughout the world (1). In the United States, over thirty-seven thousand people die each year. Also 2.35 million people are injured or disabled in the United States due to related accidents. In the United States, vehicle accidents are the largest leading factor of unintentional death.

Engineering Goal/Hypothesis

The engineering goal of this experiment is to test and prototype a better reinforcement bumper using six interventions. The six interventions are: Styrofoam, Bubble Cushion Wrap, D3O Recoil Pad, Airtech Recoil Pad, the Original Bumper Covers, Compression Spring, and the Bumper Covers. The hypothesis of this experiment is that a superior bumper reinforcement system with an intervention measured by a PCB force sensor can be found.

Purpose

The purpose of this experiment is to design and create a better bumper reinforcement that can help with the overall collision impact. Ultimately, this experiment would help decrease the amount of significant damage to the vehicle and with further development save lives.

Relevant Equations

This project is designed to replicate actual bumper to bumper impacts. Understanding the physics behind this experiment is important, as this will allow one to determine the force involved. The next section shows the equations that were used to find the amount of force that the impact system delivered.

PE = KE	Potential Energy = Kinetic Energy, by the law of conservation of energy
$mgh=\frac{1}{2}mv^2$	For a simple drop test m = mass, h= height, g = Acceleration of gravity, v = velocity at impact.
$v=\sqrt{2gh}$	Velocity at impact is equal to the square root of two times gravity's pull times height
$W_{net}=\frac{1}{2}mv(final)^2-\frac{1}{2}mv(initial)^2$	the work principle
$W_{net}=\frac{1}{2}mv(final)^2$	In this drop test application, the ½ mv(initial)² part of the work principle equation is equal to zero, because the initial velocity is equal to zero. This is where the concrete mass gets included.
$Fd=W_{net}$	The net Work (Wnet) done during an impact is equal to the average force of impact multiplied by the distance travel during impact
$F=W_{net}/d$	Divide the distance that was traveled during the impact to find force
$F=\frac{1}{2}(mv^2)/d$	This is the final equation to find the force.

The control which was a steel on steel impact was calculated to find that the force is equal to 980,000 newtons. It gets this high because the of displacement of steel is .0001. The mass of the object is 100 kilograms, the gravity is equal to 9.8 meters per second. The height of the drop was .1 meters off the base.

Methods

Phase 1 Drop Tower Construction:

Put on glasses and work gloves. Obtain two 10 centimeters by 15-centimeter parallel vertical beams to be used as tower pillars. Separate them so they are 137 centimeters apart and vertically parallel. Attach them to garage rafter as necessary. Take the garage rails and secure one onto each of the beams, so they are facing the same way. Make sure that the rails are touching the ground. Take another 10 centimeter by 15-centimeter beam, attach the winch to this beam with bolts, then place it at the top of the two parallel beams. Build a level floor at the bottom of the vertical beams able to withstand repeated substantial impacts.

Figure 1: Phase 1

Phase 2 and 3 Impact Bumper Beam Construction and Potential Energy Increase:

Remove a 2005 Jeep rear bumper reinforcement. Take the bumper covers off the bumper. Once you have stripped the bumper, obtain the four garage wheels and the four garage wheel brackets. Find a 10 centimeter by 15 centimeter wood that fits into the bumper and place the brackets for the guide wheels one on top and one on the bottom piece of wood. Secure them by putting a bolt through the wood and attaching the brackets with the bolt. Place these two pieces of wood into the bumper. Set the bumper into the rail system, using rubber grommets so the brackets do not slip out of the wheels. Obtain a 1.25 square centimeter piece of metal bar that is 91 centimeters long and place it in the lower rim of the bumper and secure it with bolts. Place the 100-kilogram piece of low profile concrete (step concrete), onto the bumper. Secure the concrete with three 340 kilograms ratcheting tie-downs. Next take the 3-meter chain and connect to the bumper. After this step is done, take the Clevis slip hook and connect it to the two ends of the chain, take the slip pin out, and replace it with the 121 centimeters 1.5-millimeter diameter rod. Pull the winch down and connect the Clevis hook with the galvanized swiveling shackle. Winch this system up slowly and controllably. Drop it from 5 cm as a proof of concept. Continue to raise the system and eliminate points of friction in the system, to achieve a guided free drop.

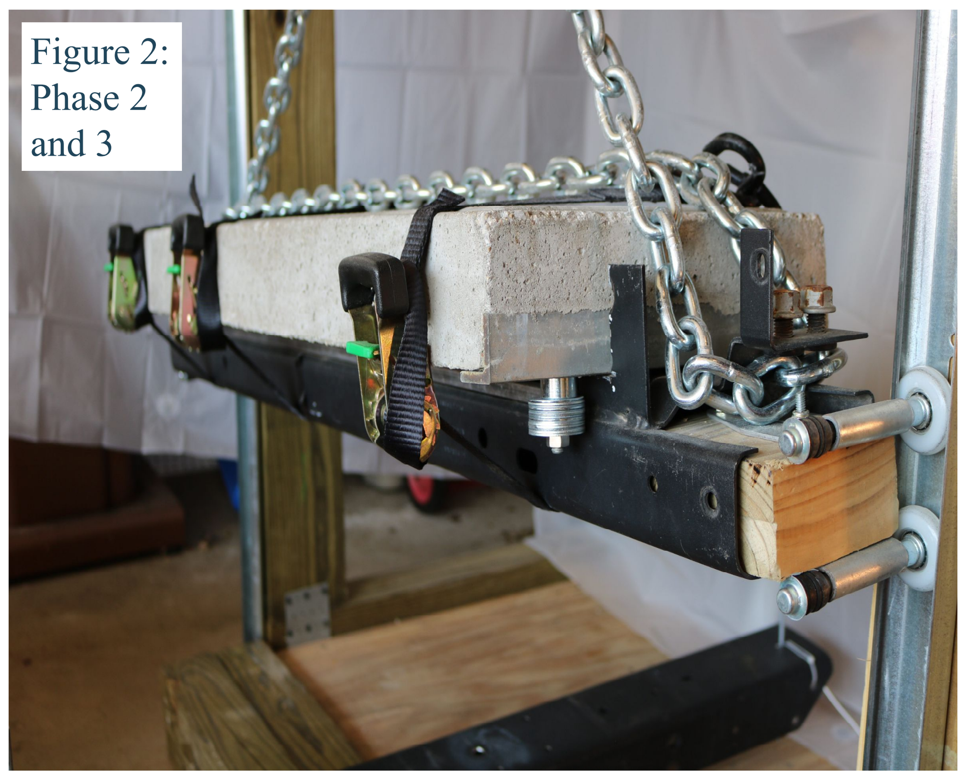


Figure 2: Phase 2 and 3

Phase 4 Bumper Reinforcement Instrumentation:

Take the front bumper off the 2005 Jeep Wrangler and take off the plastic parts. Create a custom piece of wood that holds the PCB Piezotronics 208C03 Force Sensor into so it fits securely into the bumper. Plug the sensor into Digital ICP Signal Conditioner and then into the computer. Download Spectra plus RT onto a computer. Change settings in the software to optimize impact capture. Place the bumper underneath the impacting beam/bumper with the piece of wood on the raised floor from Phase One. The bumper should be facing the other bumper to make sure the bumpers are perpendicular to one another. Perpendicular placement will decrease offset impacts.

Figure 3: Phase 4

Phase 5 Testing Phase:

Test the bumper on the ground with different interventions. A few interventions that were used were: Styrofoam, Bubble Cushion Wrap, D3O Recoil Pad, Air Tech Recoil Pad, and the original bumper covers. Another intervention that was tried was a Compression Spring system made from a metal plate and a spring. Every intervention was tested four times. Put all the interventions on the top of the bumper where the two bumpers will impact. The impacting bumper was dropped .1 meter from the top of the intervention each time. Open the Spectra RT software, and start testing the system with and without interventions. Save the results on the computer.

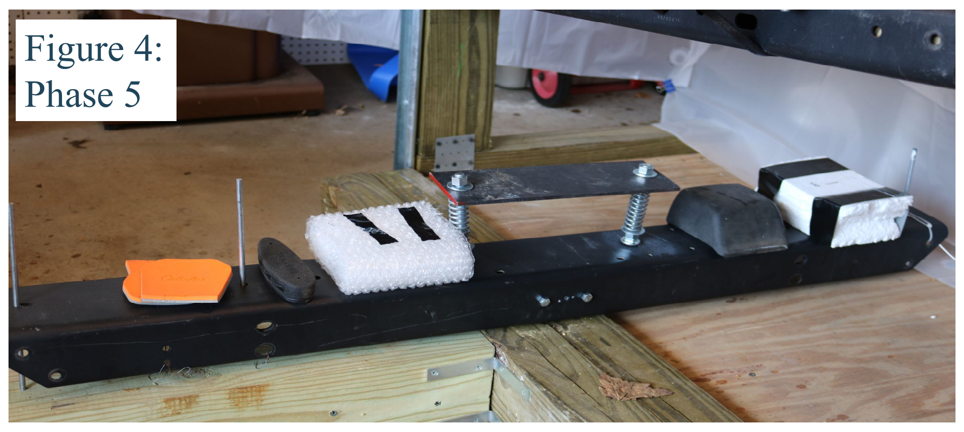


Figure 4: Phase 5

Figure 6 (below): shows the power the comparison output of the differential impacts between the control which is no intervention (left) and the intervention of D3O (right).

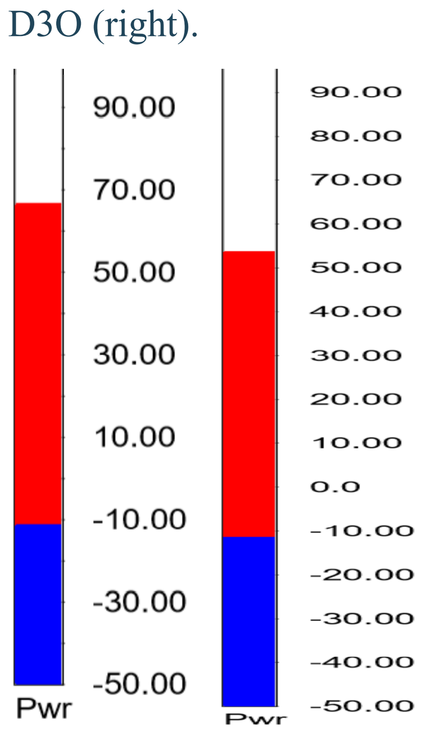
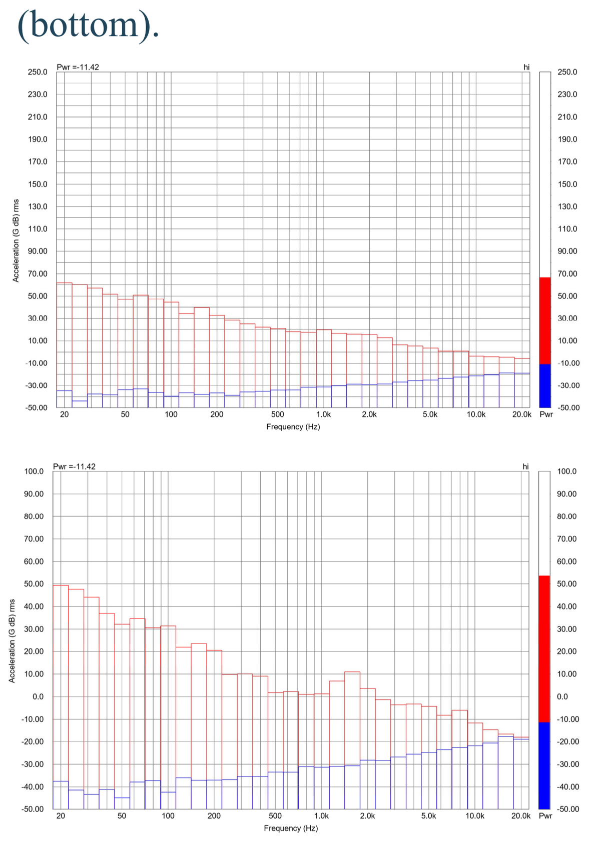


Figure 7 (below): Shows comparative examples of raw data output from the Spectra RT software, control (top) D30 (bottom).



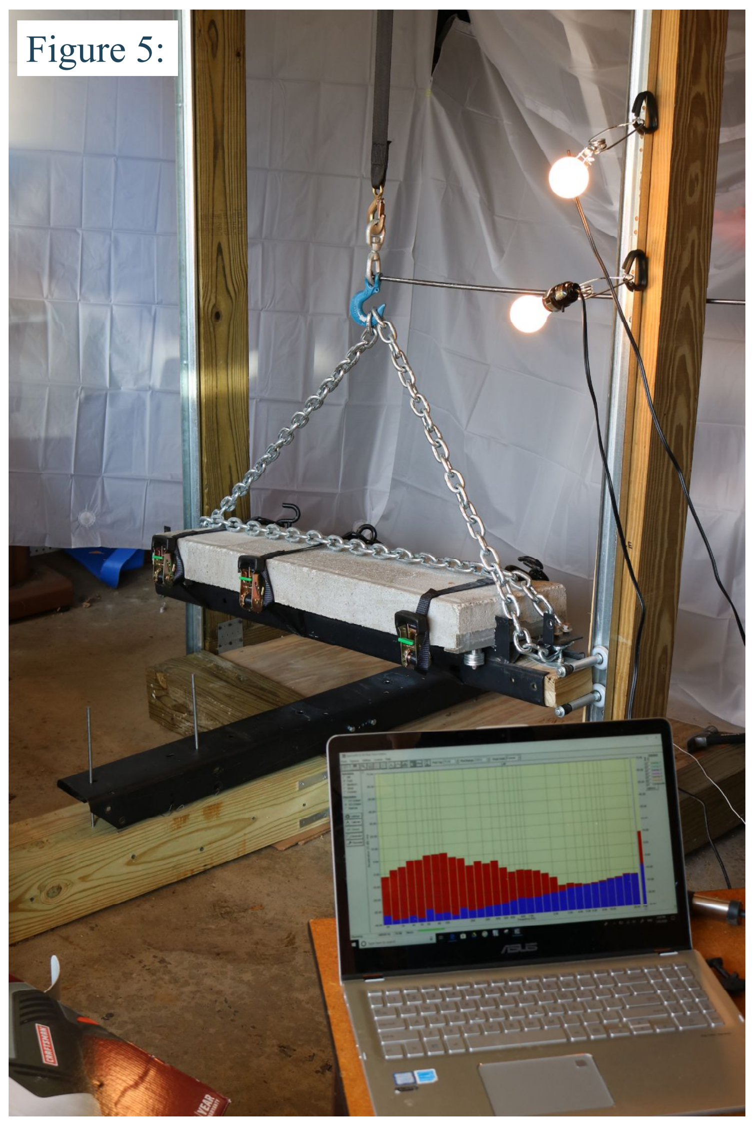


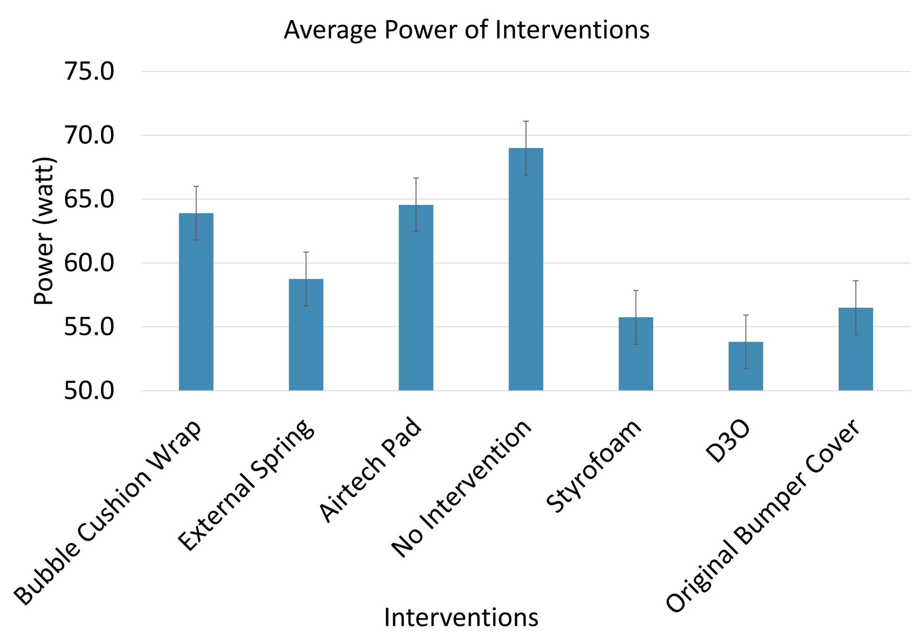
Figure 5:

Results

Figure 8 (below): This figure below shows the different intervention with a side by side comparison.

Interventions:	Trial 1	Trial 2	Trial 3	Trial 4	Average
Bubble Cushion Wrap	63.7	63.8	64.2	63.9	63.9
External Spring	58.1	57.8	59.8	59.3	58.8
Airtech Pad	63.7	65.8	64.2	64.5	64.6
No Intervention	68.7	69.1	69.0	69.2	69.0
Styrofoam	55.6	55.7	55.8	55.9	55.8
D3O	54.3	53.8	53.5	53.7	53.8
Original Bumper Cover	56.8	56.3	56.4	56.5	56.5

Figure 9 (below): This figure shows the average of the power measured by the sensor with the interventions



Power Analysis

This is done to determine the number of trials for testing.

Power=Φ(−z1−α/2+|μ0−μ1|∗n−−√/σ)

Power=Φ(−1.96+|69−53.8|∗2−√/0.3)

Power=Φ(99.373)=1=100%power

μ_0= population mean

μ_1= mean of study population

n= sample size of study population

z= critical Z value for a given α

σ= variance of study population

z= critical Z value for a given α

α= probability of type I error (usually 0.05)

β= probability of type II error (usually 0.2)

Φ()= function converting a critical Z value to power

Study Parameters:	
Mean, population	69
Mean, study group	53.8
Subjects, study group	4
Alpha	0.05

Conclusion

In this experiment, a new exploration was made towards improving the safety profile of car bumper reinforcements. The importance of making a better bumper reinforcement system is to decrease car damage and to decrease occupant injuries. To accomplish this task, actual real bumper reinforcements were tested. A robust drop tower was constructed. This was done to study six different interventions, which were measured with a Piezo Electric Force sensor. In the end, the engineering goal was met. Six prototypes of a better reinforcement bumper system using were completed.

The hypothesis was supported that a superior bumper reinforcement system, as measured by a PCB force sensor, could be designed and successfully demonstrate superior impact power over stock bumper blocks and the control bumper. All interventions performed better than if there was no intervention. Most interventions cost ten dollars or less.

After further testing and prototyping, this effort may be helpful and save considerable money and injuries. In 2017, accidents cost people seventy five billion dollars in medical expenses and work loss(4). On average, 1.25 million people die each year from vehicle related accidents (1). An additional twenty to fifty million people are injured or disabled each year in vehicle accidents throughout the world (1). This means the cost of an average accident for one person that gets hurt in an accident is fifteen hundred dollars. In the future, other interventions may be tried to help even more to help lower the mean peak even more, resulting in a safer car. After more testing of the best intervention, a car could be then built and tested to see the true difference of the old bumper against the new bumper with an intervention. Optimally, the car design won't even need to be flawed or have a weird bumper that sticks that out like vehicles did from 1973 to 1982, due to the 5-mph bumper.

All Figures were made by the investigator