Development of Ballistic Impact Device for Measuring the Impact Energy of Powder-Metal Bullets

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Abstract

In this report the development of a device that could accurately measure the ballistic impact force of powder metal bullets was carried out. The main bullets used were 155 grain frangible bullets shot from a .45 caliber pistol. Additional tests were made using 230 grain copper jacketed lead bullets shot from a .45 caliber pistol, and 115 grain copper jacketed lead bullets shot from a 9mm pistol. In order to measure accuracy of the device the distance that the force of the bullet compressed a spring was compared to the values that were calculated using weight, velocity, spring tension and other factors. The results showed that the device was able to measure the impact force of the bullet with nearly 95% accuracy. The implications of these results are that the device can be used to compare impact forces of various bullets without the need of various calculations.
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1. Introduction

There are a variety of different types of impact that can be imparted on an object [1]. These impacts include low velocity, intermediate velocity, and high velocity or (ballistic). Low velocity impacts are at speeds of approximately 1-5 feet per second and can be measured by using standard testing methods involving dropping a weight from table height to the floor. Intermediate velocity impacts are in the range of 25-300 feet per second. The forces of these impacts are measured by using a gas gun where gas pressure dictates the velocity of the moving object [1]. The third type of impact is ballistic impact which includes speed from 300-3000 feet per second. Objects that are in this category include rockets and various bullets.

Lead bullets have a wide variety of uses including: hunting, shooting, and industrial purposes. One way that lead bullets are used in industry is for the process of making cement. The cement is heated to temperatures up to 1450°C in a kiln and often gets stuck to the sides. Because the temperature is so high, the cement cannot be scraped off manually. For this reason an 8 gage shotgun slug is fired into the wall of the kiln, knocking the cement off [2, 3, 4].

Dozens of these lead bullets can be shot into each batch of cement made, and thousands of batches are made yearly. Lead is the current method [3, 4] because the vaporization of lead occurs at 1750°C and the temperature of the flame that a coal powered kiln can reach is over 2000°C. This means that after the bullet hits and knocks the stuck cement off it will vaporize and not be in the product. Power plants use the same process to knock off build ups of soot in the smoke stack known as clinkers. The problem with lead is that it is poisonous to breathe. Each shotgun slug weighs two ounces. With hundreds of thousands of shots in a given year, tons of vaporized lead is being introduced to the atmosphere and being breathed in. Children are extremely susceptible to lead poisoning and can experience neurological effects with less than 10
An accumulation of lead in the blood due to prolonged exposure can cause tremors, hallucinations, kidney failure, and even death. Tons of toxic lead could be kept out of the air if there was a better option for getting cement off the sides of cement kilns. Bullets made of copper or iron are an alternative, however, these metals have high melting and vaporization temperatures, and will stay in the cement leaving it lumpy and less desirable. Materials that are non-toxic and environmentally friendly, but powerful enough to knock loose the stuck material, would be much more desirable. Unfortunately, there is current no way to determine the ballistic impact force of a bullet to know if it would be a viable substitution. By developing a product that could accurately measure the impact force of a bullet, one could then develop a bullet that meets all the needs that a cement manufacturer could want without using lead.

2. Background

Since 1998, SinterFire Inc. (https://www.sinterfire.com) has been the leader in lead-free, frangible projectiles. All SinterFire products are made using an exclusive powder metal (PM) processing to produce bullet components that are the industry standard worldwide and the benchmark by which all “green” (lead-free) and frangible (safer) ammunition products are manufactured.

For this project, SinterFire has requested Penn State DuBois to develop a device that can accurately measure the impact energy of a bullet. The current method is by doing calculations regarding velocity and the weight of the bullet but some other factors aren’t taken into account. Other methods involve shooting the bullet into sand and noting the penetration depth. In this method a mound of sand with known density and thickness is shot into. The bullet is then dug
out of the mound and everything from the penetration depth to the deformation of the bullet is accounted for in determining the impact of the bullet. This method however, required one to find the bullet and hope that it did not hit a denser patch of sand or divert into another direction. The most common devices used are high speed cameras and various sensors that are generally very expensive and only measure things such as impact velocity and record pictures of the moment of impact [6]. Other devices use a laser line velocity sensor (LLVS) to measure the ballistic impact on the material in use [7]. This method uses a highly sophisticated alignments of lasers to measure the impact force along with velocity and other data. Although it works, it is not practical to have sensitive equipment in close proximity to a bullet that will have shrapnel associated with it. A device that could measure the energy directly without the use of complex math or expensive cameras and lasers would be a beneficial tool to SinterFire. The goal of this project was to design a mechanism that can accurately measure the impact energy of a bullet. This has been accomplished by using resources and prior knowledge of dynamics and other engineering principles along with research into the project including which ammunition works best and materials selection.

3. Experimental Approach

The first step in building a device that could measure the impact energy after being given the task of creating this device was to identify the criteria. It is known that bullets fragment on impact on a hard surface because of lead’s soft nature. Thus, all parts of the device would have to be tough enough to withstand being hit with shrapnel at some time. This criterion immediately ruled out fine instrumentation, such as computers, for a measuring device. The device also had to be small enough that it could be transported, but heavy enough that it wouldn’t fall over or get
pushed backward by the force of a standard bullet. Also, the device had to withstand being shot by a bullet without breaking and do it accurately. Literature review was done to find existing ways of measuring impact energy. The use of kinematics and kinetics equations is obviously a way to find a theoretical value of what the impact force should be, however this method cannot take all factors into account, and may not be appropriate for determining the actual impact force. It does however serve as a way to check if the device is close to the theoretical value; so this was used later to test the device.

Next, several ideas were generated from the research. One device that stood out was called a ballistic pendulum [8]. This device was not used to calculate the ballistic force of a bullet but was instead used to impose a ballistic force onto an object. A few modifications of this device would allow one to shoot it and measure the distance the pendulum swings to get the force that was applied. Another idea would involve shooting a metal plate using a spring for resistance. The distance that the plate traveled multiplied by the resistance of the spring would give the force applied to the plate. Upon careful consideration of all ideas, it was determined that the plate attached to the spring would give the greatest chance of success.

3.1 Building the Device

Now that the decision was made on what to build the decision had to be made how to build it and what to test it with. To be able to handle the impact of a bullet the plate that was to be struck must be made of a hard wear-resistant material. A mild steel plate was selected to test if it would stand up to being shot several times without much denting or cracking. Too soft of a plate would leave a large dent in the metal. This would result in poor measurements because energy went into denting the metal rather than pushing it back. However, a brittle material could
result in a break that would ruin the entire apparatus. Several different calibers of bullet were used in the test, including a .22 long rifle, a .222 using a lead bullet, and a .222 using a copper jacketed bullet [Figure 1].

![Figure 1: Dents due to shots with .22, .222, and .222 jacketed on mild steel plate](image)

The results were that the .22 did no or little damage to the plate, the .222 lead bullet had some significant damage associated with it, and the .222 copper jacketed bullet nearly went through the mild steel target. This test proved that a mild steel plate was too soft and weak to be used in this project. It was also determined that a rifle bullet may be too powerful to get good experimental data; so pistols would be used from then on. More specifically, frangible bullets would be used. Frangible bullets are made from powdered metal (PM) and once they hit a hard target break apart into many pieces leaving only powder behind. In the next experiment a stellite plate was clamped to the mild steel plate. Stellite is a cobalt-chromium alloy that has a high
level of hardness and toughness and is also corrosion resistant. A 9mm jacketed bullet and a .45 jacketed bullet were then fired at the stellite plate [Figure 2].

![Figure 2: Dents due to shots with the addition of a stellite plate](image)

This resulted in little damage to the plate. The dents measured less than 1/32 of an inch which then made the amount of force used to dent the plate negligible in the calculations. Now that a material was selected for use, the device could then be built. This process involved early sketches, more advanced drawings and then the final design. The first step in building this device was to weld the stellite plate to the mild steel plate. A metal bolt was then welded to the back of the plate. This is where the spring is located in order to keep the spring from binding. Then, a metal angle iron was welded to the bottom of each sides of the plate, which was the part of the device that moved. Separately, two more angle irons were welded onto the sides of a rectangular metal base plate. A vertical piece of metal with a hole in it was then welded to the center of the base plate. The hole would allow the bolt to pass through it and would cause the spring to collapse on the vertical piece of metal. A sliding mechanism consisting of two thin pieces of metal with small rollers between them was then bolted onto both of the angle irons on
the base plate. Finally, the angle irons on the moving portion were bolted to the sliding mechanism. Figure 3 shown the final prototype.

Figure 3: Final Fabricated Impact Tester

3.2 Testing the Device

Before the device was shot at, the velocities of the bullets that were being used had to be measured. In order to accurately measure the speed a chronograph was used [Figure 4]. The chronograph was placed on a table ten feet from the muzzle of the gun and pointed so that it was facing head on. After turning it on, the screen prompted whether to use feet per second or meters per second and because all other calculations were using feet and pounds the feet per second option was selected. A shot was then fired through the chronograph approximately six inches above the box as directed by the manual. The velocity of the bullet was then shown on the screen and recorded for later use. A variety of calibers of bullet were fired several times in order
to get a more accurate reading. This data was later used in the calculation of the accuracy of the device.

![Chronograph](image)

**Figure 4:** Chronograph used to measure the speed of various bullets

Next, three different bullets were selected to do the bulk of the experiments. The bullets that were selected were a 115 grain copper jacketed 9mm, a 230 grain copper jacketed .45 caliber bullet, and a 155 grain frangible .45 caliber bullet. The primary bullet that was being tested was the frangible bullet. Frangible bullets are made from powdered metals and are sintered to a density that will allow them to easily break apart when hitting a hard structure. This would cause less damage to the plate and give more accurate results due to the lack of energy being lost from the velocity of large pieces of bullet after the impact. Also, the frangible bullets allowed for closer shooting distances while still being safe. The device had to be on a level surface with the
plate perpendicular to the shot being fired. To achieve this a wooden table was set up ten yards away from the muzzle of the gun. Ten feet was the distance that the velocity was measured at so this would give an accurate velocity at the impact of the bullet. Using a level it was ensured that the device was perfectly flat on the table. The base plate was clamped to the table to keep the entire device from moving back when being shot. The spring was then placed over the rod on the back of the plate and slid into a position where the spring was tight against the plate being shot and vertical plate describe earlier. A pen was secured to the back of the moving assembly and was placed on a blank piece of paper. The position of the pen was marked because after being shot the energy given by the spring would often push the plate further back than the original position. Then, a table was set up to enable the shooter to accurately shoot the metal plate. A shot was then fired at the plate using personal protective equipment (ear and eye protection). After the shot, the paper with the mark on it was removed and a new piece was put in its place. The plate was moved back into the proper position and the position of the pen again was noted. The line that had been created by the shot was then measured using calipers that were accurate up to one thousandth of an inch. The distance was then marked on the paper along with the date and what bullet and caliber were used. This process was repeated with every shot.
4. Results

Table 1 and Table 2 summarized measured velocities and spring compression, respectively, for the three types of bullets used.

**Table 1: Measured velocities**

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Bullet Weight and Caliber</th>
<th>Velocity (ft/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>115 grain 9mm</td>
<td>1113</td>
</tr>
<tr>
<td></td>
<td>230 grain .45</td>
<td>816.2</td>
</tr>
<tr>
<td></td>
<td>155 grain Frangible .45</td>
<td>1096</td>
</tr>
<tr>
<td>1</td>
<td>1113</td>
<td>816.2</td>
</tr>
<tr>
<td>2</td>
<td>1063</td>
<td>811.1</td>
</tr>
<tr>
<td>3</td>
<td>1110</td>
<td>814.8</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>1070</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>1066</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td><strong>1095</strong></td>
</tr>
<tr>
<td><strong>Std Deviation</strong></td>
<td></td>
<td><strong>23</strong></td>
</tr>
</tbody>
</table>

**Table 2: Measured compression distance**

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Bullet Weight and Caliber</th>
<th>Compression (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>115 grain 9mm</td>
<td>0.834</td>
</tr>
<tr>
<td></td>
<td>230 grain .45</td>
<td>1.015</td>
</tr>
<tr>
<td></td>
<td>155 grain Frangible .45</td>
<td>1.000</td>
</tr>
<tr>
<td>1</td>
<td>0.834</td>
<td>1.015</td>
</tr>
<tr>
<td>2</td>
<td>0.757</td>
<td>1.137</td>
</tr>
<tr>
<td>3</td>
<td>0.88</td>
<td>1.246</td>
</tr>
<tr>
<td>4</td>
<td>0.782</td>
<td>1.113</td>
</tr>
<tr>
<td>5</td>
<td>0.794</td>
<td>1.148</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>1.235</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>1.045</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>1.115</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>1.193</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>1.208</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td><strong>0.809</strong></td>
</tr>
<tr>
<td><strong>Std Deviation</strong></td>
<td></td>
<td><strong>0.043</strong></td>
</tr>
</tbody>
</table>
Figure 5 shows comparison of spring compression for the three types of bullets used.

![Graph showing spring compression comparison](image)

**Figure 5**: Comparison of spring compression from three different bullets

For comparison purpose, and for checking the accuracy of the device, a calculation of the spring compression was performed. In this analytical solution, the 45 ACP 155 grain frangible bullet was used. Assuming central impact, the following equation for the conservation of momentum can be applied

\[ m_1 v_1 = m_2 v_2 \]  

where

- \( m_1 \) = mass of bullet (= 155grains/7000grains/lb = 0.02214 lb)
- \( v_1 \) = velocity of the bullet (= 1075 ft/s)
- \( m_2 \) = mass of moving plate & assembly (=15.42 lb)
\( v_2 = \text{velocity of plate & assembly after impact} \)
From Equation 1, the velocity of the plate & assembly after impact is determined as

\[ v_2 = \frac{(0.02214 \text{ lb})(1075 \text{ ft/s})}{15.42 \text{ lb}} = 1.543 \text{ ft/s} \]

The impact energy can then be calculated as

\[ E = \frac{1}{2}mv^2 \quad (2) \]

where
\[ m = \text{mass of moving plate & assembly} \]
\[ v = \text{velocity of plate & assembly after impact} \]

Hence,
\[ E = 6.85 \text{ in-lb} \]

Assuming conservation of energy, the amount of spring compression can be determined as:

\[ x = v \sqrt{\frac{m}{k}} \quad (3) \]

where
\[ x = \text{spring compression} \]
\[ m = \text{mass of moving plate & assembly} \]
\[ v = \text{velocity of plate & assembly after impact} \]
\[ k = \text{spring constant} = 10 \text{ lb/in} = 120 \text{ lb/ft} \]

Thus
\[ x = 1.543 \text{ ft/s} \sqrt{\frac{15.42 \text{ lb}}{(32.2 \text{ ft/s}^2)(120 \text{ lb/ft})}} \]

\[ x = 0.0975 \text{ ft} = 1.170 \text{ in} \]

This value compares very well with the measured value in Table 2 of \( x = 1.105 \text{ in} \). This indicates that the accuracy of the prototype is

Accuracy = \( \frac{1.105}{1.170} = 0.944 \) or 94.4%

The impact force, \( F \), can then be calculated as:

\[ F = kx \]

\[ F = (10 \text{ lb/in})(1.105 \text{ in}) = 11.05 \text{ lb} \quad (4) \]

**5. Discussion**
The results of the tests yielded good information that was then used to determine the accuracy of the device along with the impact forces associated with the bullet. Table 1 presents the results of the velocity measurement with the chronograph for the 9mm and the two different types of .45 bullets. Because the frangible bullet was to be used as the standard, it was the bullet that was measured the most. As expected the bullet velocities varied with each shot. The difference between shots were nearly eleven feet per second. One of the reasons for this difference could be the fact that the shells that were used were factory loaded. Generally, bullet casings are filled with a certain amount of grains of powder by an automated system. One grain of powder more or less can get into each casing causing little or no effect on the trajectory of the bullet but can cause a few feet per second difference in velocity. Other factors that can contribute to the observed differences in the velocities of the bullets include the possibility that not all of the powder burning, bullet seating in the neck of the casing, and environmental factors as well. Because the fragments of the bullet could struck and break the chronograph, it was decided to use the average of the velocities when comparing the calculated compression versus the measured and use the standard deviation to see whether it was accurate or not.

Table 2 shows the results of the compression measurements for the 9mm, .45 caliber jacketed, and the .45 caliber frangible bullet. The average and standard deviation were also calculated to show the precision of the device. By comparing the compressions of each bullet it is apparent that the .45 frangible had higher compression than the 9mm. A larger bullet moving at nearly the same speed would have more force associated with it. What may be surprising is that regular .45 caliber bullet had a greater spring compression than the frangible bullet despite being much slower. Some people may believe that a faster bullet will result in a more forceful bullet but that is clearly not the case. For easy comparison, the three bullets with their
compressions are shown in Figure 5. The differences within each bullet type can be attributed to a variety of factors. One factor being that the bullet velocities may have changed from one bullet to the next. The fastest velocity recorded was thirty feet per second faster than the slowest in the frangible bullet. The difference between the two velocities played a large role in the differences in spring compression. Another reason that the compressions may have been different was due to shot placement. It was discovered that shooting the plate in the middle or near the bottom yielded nearly no change in compression distance. However, a dramatic drop in compression distance occurred when a bullet hit the upper portion of the plate. This was due to the fact that the rails were on the bottom of the plate and by shooting the top of the plate a moment was created that took some of the force of the bullet away. These shots were so far out of the range of compression distance that they were not included in the average.

Equation set 1-3 lists out the mathematical process that was used to calculate the accuracy of the device. The equations used measurements such as, the weight of the plate, spring constant, weight and average velocity of the bullet to calculate what distance the bullet should compress the spring. This number was then compared to the average compression distance that was measured. Using strictly the averages for both the velocity and the compression distance it was determined that the device was more than 94% accurate when using the frangible bullets. Using the same equations it was determined that the device was accurate up to 92% for the 9mm, and 86% for the .45 regular bullets. The overall loss in accuracy can be attributed to various reasons. In all three cases the difference in velocity of the bullet would have the greatest negative impact on the accuracy. Knowing the velocity of the bullet as it hit the metal plate would drastically cut down on the loss of compression from a theoretical view and show that the device is much more accurate than calculated. However, there are other attributes
that cause a loss in energy from what was measured. When a bullet hit the plate there was some denting involved. This is part of the energy that went into denting of the plate instead of bouncing it. A plate that could resist indentation even better than stellite would cut down on this loss. When the bullet strikes the plate vibrations in the form of heat and sound are created. Although small, these factors also contribute to a loss in total energy. Additionally, the friction force from the sliders contributes to an overall loss in measurable force. The additional loss from the frangible bullets to the copper jacketed bullets can be attributed to other factors. When a frangible bullet hits a hard object it breaks into many small pieces whose velocity can be neglected due to the small sizes. When a jacketed bullet hits a hard object the bullet can fragment into a few smaller sizes that have sizable mass and need to be accounted for. Without the use of a high speed camera or other measuring devices, it is not possible for the velocities of these particles to be measured. Also, when the two jacketed bullets were fired at the plate additional precautions were made to ensure safety of the shooter. Because the small pieces of lead can be dangerous, the target was moved ten feet further back. The ten extra feet resulted in a lower velocity upon impact than the measured velocity at only ten feet. Equation 4 shows how to determine the impact force associated with the bullet.

6. Conclusion

The goal of this project was to design a device that could accurately measure the impact force of a bullet. With over 94% accuracy the development of this device has been a success. By using the conservation of momentum, kinetic energy, and elastic potential energy it was shown that the device was within seven hundredths of an inch of the theoretical compression that the force should have moved the plate. The loss in force that was read can be attributed to the
difference in bullet velocity from one shot to another, the slight denting of the stellite plate, the shot placement, and energy loss from heat and sound. Additional losses to the non-frangible bullets was caused by the large pieces of shrapnel that had measureable velocity that couldn’t be accounted for and the increase in distance from the target when shooting.

The original design and prototype were successful in measuring the impact force of a bullet however, some improvements could have been made to allow for better results. First, a metal that could resist indentation completely would lead to more accurate testing. Although the stellite is a big improvement on the mild steel plate, small denting did occur which lead to a lower measured force. Another design improvement would be putting the rails in the middle of the plate. This would allow for the plate to be shot in the center or slightly above or below without inducing a moment on the railing which decreased the overall performance of the device. In addition to the decrease in measured force, the moment will put stresses on the railing causing them to break. For more accurate shooting, a gun could be placed in a vice and properly lined up so that the same spot is shot every time. This would increase consistency and give better results. The pen apparatus that was used to mark the distance that the plate moved had a tendency to work itself lose after ten shots or more. The pen would then need to be tightened which cost time and increased errors when it was loose. An improvement on the measuring device would be beneficial.

This device could be used in many applications. As previously mentioned, 8 gage shotgun slugs are used to knock loose cement from the side of kilns. A device such as this prototype could be used to test alternative bullets that give the same force but are less detrimental to the environment. The device could also be used to test the impact force using bullets with different weight and with different amounts of powder to achieve the optimum round of
ammunition for a desired use. Also, different bullet materials could be tested to find a substitution for the current lead bullets used in hunting and sport shooting.

**Acknowledgments**

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**8.0 References**


