Lab #4.

A. C. Quillen, PHY141 Fall 2022

Reducing peak force in an impact by crushing foam

Equipment list

For each station: Red box of sensors for PHY141. Blue box of equipment for PHY141. Stand. Silver track. Rulers.

At the front of the room: spare hardware, extra boxes with spare equipment. Pieces of wet floral foam cut to about 2.5″ x 2″ x 3/4″ or 7x5x2 cm. Extra foam. Hacksaw blade for cutting foam. Corks. Rubber bands. String. Twist-ties. Scissors. Double sided tape. Glue dots.

1 Objectives

When a car is in an accident, the strength of the impact is time dependent during the impact. We can describe this dependence and in terms of the force as a function of time, $F(t)$. The momentum principle $p = dF/dt$ implies that the change in momentum

$$\Delta p = \int F(t) dt.$$

We consider a person in the car. The person's acceleration is the force divided by time. If the momentum change takes place over a longer time interval then the impact is less severe.

Cars are designed to minimize the force on passengers (and in some rare cases, the force on pedestrians or bikers that are hit by the car). To do this, car bumpers tend to crumple rather than respond elastically. Sometimes they contain foam which is crushed.

It is not necessarily desirable to have an elastic impact. If the car comes to a stop, the total momentum change is mv, whereas if the car bounces elastically, the total momentum transferred is $2mv$. By crushing or crumpling, the car can absorb energy.

Foam can act like a solid and can behave elasticity. However if the pressure on a piece of hard foam increases past a particular value, it can be crushed. Pressure is a force per unit area. The minimum compressive pressure (also called compressive stress) is known as the yield strength, σ_{crush}. We have light foam which is commonly used for floral arrangements. If you push on it moderately hard, you can crush it. However, if you drop a piece, you will also notice that it can bounce, so it can also act like an elastic solid.

If the stress is above the yield strength σ_{crush} then work is done by crushing the foam. The work done by crushing the foam is

$$W = Fd \approx \sigma_{crush} A d$$

where A is the area of the crushed material and d is the width change. Here W is the energy absorbed due to compression.

Yield strength σ_{crush} has the same units as pressure. The SI unit for pressure is Pa (Pascals) and this is equivalent to N/m^2.

In this lab, we will measure the force during an impact. We will compare impacts into foam to see what happens when the foam is crushed.

2 Procedures

2.1 Calibrating the Force sensor

- Launch the Capstone software. Plug in the the force sensor to one of the analog inputs.

  Click on the Science workshop 750 icon and use the pull down menu to choose the force sensor.

- Attach a hook to the force sensor. Attach a hook to the force sensor. Orient the force sensor vertically. Using the grey hangers and weights in the blue box, hang a mass on the hanger and attach it, with a string or twisty, to the force sensor.

- Click on the Calibration button the left in Capstone. Choose `Force sensor` and `Two calibration points`. Using the known mass and g, you can calculate what the force $F = mg$, in Newtons, that is exerted on the force sensor. Enter this force in the `Standard Value` box and click the `Set Current Value to Standard Value` button.

- Repeat this procedure with a different weight and then press finish. The sensor should now be calibrated. See Figure 1 for a screen shot of the Capstone calibration menu.

2.2 Set-up

- Set up the track at a slight incline using a stand as shown on the right in Figure 2. Put the motion sensor on this end of the track so that it faces down the track. I found I could keep it in place with a rubber band. By starting the cart at the same position and letting the cart roll down an incline, we can ensure that the impact velocity is the same in different experiments. Compute and record the angle of the incline for your track.

- Plug in the motion sensor to the data acquisition system (plug it into digital inputs 1,2) and under `hardware setup` click on a digital input and choose 'motion sensor'.

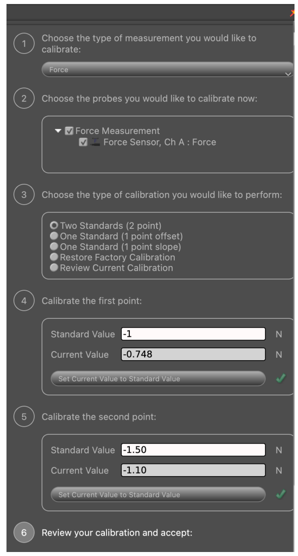

Figure 1: Calibrating the force sensor.

- Set up the force sensor on the lower side of the track as shown on the left in Figure 2. You need to screw the bumper holder onto the track and then screw the force sensor onto the bumper holder. Connect the bumper with a circular cap to the force sensor. Using a piece of double sided tape or a glue dot, stick a cork into the cap, as shown in the Figure on the left in Figure 2.
- Increase the sampling rates of both force sensor and motion sensor. You can do this with a drop down menu at the bottom of the Capstone software. I found that 10kHz was good for the force sensor and 100 Hz was high enough for the motion sensor to measure pre- and post-impact velocities.
- Record an impact.
- Take a look at the shape of $F(t)$. The force should not go above about 70N and the curve should not have a flat top. If it has a flat top, the force sensor is saturated and you need to reduce the incline of your track.
- Try to measure the impulse as shown in Figure 3.
- Check that you can measure pre and post impact velocities using the motion sensor. For the post impact velocity, it would be the velocity just after the impact. If the cart rebounds, the velocity changes sign.

Figure 2: The lab setup. Left: The force center is held by a bumper holder. A cork is held onto the bumper with a piece of double sided tape or a glue dot. Right: the right the track is held up by the stand so that it is slightly inclined. The motion sensor is held with a rubber band. I found I could not incline the track by more than a few degrees without going over the force sensor limits when the cart collides with the force sensor.

- Check that $m\Delta v$ is consistent with the impulse. The cart mass is about 0.5 kg.

2.3 The experiments

You have the following goals:

1. Compare the shape of the impulse, $F(t)$, for different impacts that have the same collision velocity. Try to understand what influences peak value, duration and shape.
2. Estimate the yield strength of the foam and how much energy it takes to crush it.

To achieve these goals

1. Run experiments without any foam, as shown on the left in Figure 2.
2. Run experiments as shown in Figure 4 with the wide end of the cork facing outward.
3. Reverse the direction of the cork and run some more experiments.

The area of the cork facing the foam will determine the region of foam that is crushed. Your estimate for yield strength should depend on the area and depth of foam that is crushed. You will want to measure the area of both sides of the cork and the depth that foam is crushed during foam crushing experiments.

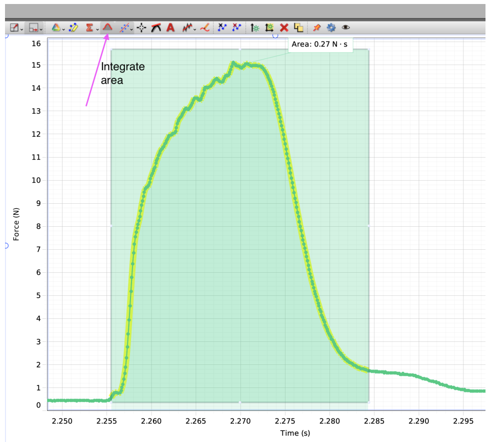

Figure 3: You can measure the impulse by integrating over the force in a highlighted region. First set up a highlight region. Then click on the area icon to integrate over the force. For this run, the cart smashed into a piece of foam which was crushed. Notice that at around 2.26s, the slope of the force curve changes.

3 Analysis and Discussion

Compare the shape of the force curves for each type of impact. How does the duration, maximum height and shape vary?

Compare the Δv values for the different impacts. How much energy is absorbed by the foam?

Estimate the yield strength of the foam.

Estimate how much energy it takes to crush the foam.

4 Feedback

Don't be afraid to send comments to your professor or lab TAs on the labs. This is a new lab, so comments are particularly appreciated!

Note: it would be better to have more elastic collisions in the absence of the foam so that we could see a larger difference in the energy lost in the collision.

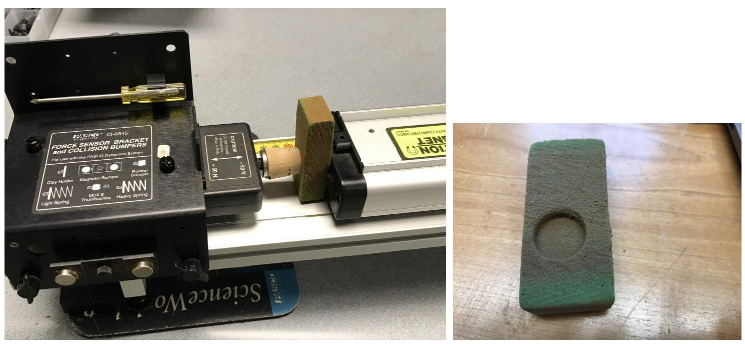

Figure 4: Left: A piece of foam is inserted in front of the cork. When the cart hits the foam, the foam is crushed by the cork. Right: After the impact, the foam is crushed by the cork.