Testing the Impulse Theorem via Collision Barriers

Materials: *Dynamics cart (without spring bumper), picket-fence flag dynamics track with impulse-collision bumper set, force probe, (1) PASCO Smartgate Photogate, computer with PASCO Capstone software and a short ruler*

1 Purpose

The goal of this lab is to test the impulse-momentum theorem. This will be done by performing collision experiments using a force sensor and photogate timer and four different collision barriers.

2 Introduction

The impulse-momentum theorem states that the impulse experienced by an object is related to the change in momentum of the object. The algebraic relationship is

$$\vec{J} = \Delta\vec{p} = m\vec{v_f} - m\vec{v_o} \tag{1}$$

but impulse ($\vec{J}$) is also

$$\vec{J} = \overline{\vec{F}}\Delta t \tag{2}$$

Here, $\overline{\vec{F}}$ is the average force acting *on* an object through an interaction time of Δt.

The impulse during a collision can be directly measured with a force sensor. The force sensor is a pressure sensitive electronic device which converts applied forces into a change in voltage. This voltage change is interpreted as a force by the computer software. Measuring the force several hundreds of times a second allows us to map out the force experienced during a collision as a function of time. Then we use the software to determine the area under the resulting curve which is the impulse experienced by the system.

3 Procedure

In this experiment, the experimenter will be using two devices: A photogate and force sensor. An example setup is shown in Fig. 1. As always, read and follow the directions carefully.

3.1 Equipment Setup

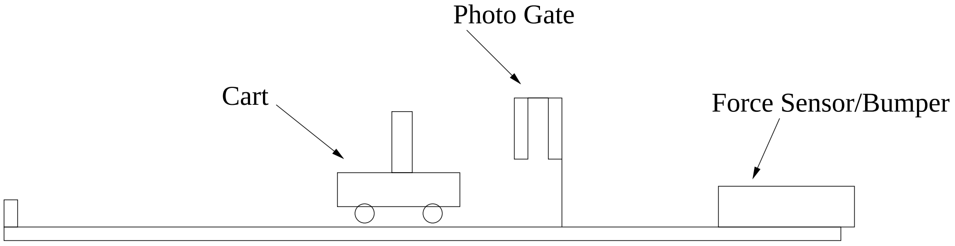

Figure 1: Setup of the impulse-momentum experiment showing the general placement the components.

1. Measure and record (a) the mass of the dynamics cart with the flag and (b) Smartgate Photogate separation distance, S. (Look for a set of small holes within the 'U' part of the photogate, you should find S to be between 1 and 2 [cm]). If you are not using a Smartgate photogate then you will need the flag width.)

2. Connect the SmartGate to the 'PasPort 1' channel and force probe to the 'Analog A' channel.
3. If an experiment file has been provided, open the file and verify the sensors are appropriately configured. If no file has been provided then do the following to setup the sensors.
    - Under the 'Hardware Setup' tab, add a force probe and Photogate to the appropriate channels
    - If using the 'PASCO Smartgate', configure the timer to use both of the built-in photogates. If you have a traditional photogate you will need to configure the timer to measure the *time the photogate is blocked* and then measure the *width of the flag* used in the experiment.
    - Set the sample rate of the force probe to 500 Hz.
    - Create a plot of the '*Measured Force, F (N)*' versus '*Time, t (s)*'.
    - Create a table to display the *time photogate blocked* and show at least 3 digits after the decimal.
    - [Optional] Create a column in your table to calculate the speed of the cart through the gate.

3.2 Data Collection

Notes: The procedure is the same for all bumpers and the order in which your data are collected is not important. However, you should report your data and results in order of (1) Magnetic Bumper (2) Weak Spring (3) Stiff Spring (4) Rubber bumper; unless your instructor specifies otherwise. Not every table will have all of the bumpers, so work with what you have and then borrow from another group, as needed. Do not lose any of the collision bumpers.

1. Attach a bumper to the force sensor. Ensure that the sensor is properly seated and snug to the mounting block (finger tight is fine; any more than that and you are likely to break something, which is *not* allowed).
2. Properly seat the flag on top of the dynamics cart
3. Ensure the photogate is vertically positioned so that the appropriate part of the flag blocks the beam as it passes
4. Position the photogate so that the flag completely passes through the gate before the collision begins (~ 30 [cm] for the magnetic bumper works fairly well; the others can be closer).
5. Press the 'tare' button on the force sensor. This zeros the sensor and *must* be done before *every* run.
6. One person now needs to brace the track so it does not shift during the collision.
7. Start recording data and then gently send the cart through the photogate towards the bumper. It may take several trials before finding a good speed for the bumper in use. Note a few things
    - The cart should be rolling freely *before* it enters the photogate.
    - The cart should be sent *fast enough* to complete the collision and then pass back through the photogate but *slow enough* so the cart wheels do *not* bounce out of the grooves on the track.
    - The cart should *not* come into physical contact with the magnetic bumper.

4 Analysis

1. Record both time (and velocity) values for each run. The velocity before the collision v_i and after the collision v_f should have opposite signs appropriately reflecting the direction of travel. Use the convention that produces a *positive* change in momentum $\Delta\vec{p}$.
2. Use the cart's mass and measured velocities to calculate the cart's total change in momentum ($\Delta\vec{p}$) during the collision. (This is one measure of the impulse via Equation 1.)
3. Measure the impulse ($\overline{\vec{F}}\Delta t$ c.f. Eqn 2) by
   (a) Scaling the *Force* versus *Time* plot so the measurement of the collision dominates the plot.
   (b) 'Measure' $\overline{\vec{F}}\Delta t$ by using the plot tools (i) to select the relevant data and then (ii) determine the area under the curve [use the mouse to hover over icons until you find the relevant tool].
   (c) Record this *area* value and save the plot with a 'screenshot' that is then pasted in a document where you can add an appropriate title, axes labels and notation for the measured area.

5 Questions

Address the following points on a clean sheet of paper.

1. Create a table (like Table 1) to summarize the experimental data. You should have a row for each collision and columns for (a) Initial time between gates, Δt_i; (b) Initial velocity, v_i; (c) Final time between gates, Δt_f; (d) Final velocity, v_f; (e) Total change in momentum, $\Delta\vec{p}$; Impulse measured via area under the curve, $\overline{\vec{F}}\Delta t$; Percent difference between $\Delta\vec{p}$ and $\overline{\vec{F}}\Delta t$.
2. Under the data table, show one of each parameter calculated for the summary data table: $\vec{v}_i = S/t_i$, $\vec{v}_f = S/t_f$, $\Delta\vec{p}$, % Diff= $\frac{\Delta\vec{p}-\overline{\vec{F}}\Delta t}{0.5(\Delta\vec{p}+\overline{\vec{F}}\Delta t)}$.
3. Which of the bumpers best demonstrate the impulse-theorem? Support your claim.
4. Which of the bumpers is the worst at demonstrating the impulse-theorem? Support your claim.
5. On each plot, mark where the collision starts as t_1 and where the collision ends as t_2. Then calculate the duration of the collision, Δt. Calculate the average force $\overline{\vec{F}}$ for each bumper.

Table 1: Summary data table for impulse-theorem experiment.

	t_i [s]	v_i [m/s]	t_f [s]	v_f [m/s]	$\Delta\vec{p}$ [kg m/s]	$\overline{\vec{F}}\Delta t$	% Diff
Magnet							
Weak Spring							
Stiff Spring							
Rubber							

References

- OpenStax, *Physics*, Chapter 8
- *Physics*, Cutnell and Johnson, 8th Edition, Chapter 7