Impulse and momentum

SOCRATES MINERVA
Programme
99843-CP-1-2002-1-PL

Data acquisition (TI 83/TI84)

Objective:
In this experiment our objective is to compare the impulse on a cart and its momentum change. The motion of the cart will be studied with a CBR when the cart collides with a force probe. The force probe is connected via a CBL or a LabPro to a graphing calculator. The CBR is connected to another graphing calculator.

Before setting up the experiment make sure that you have the program IMPULSE in one TI-83/TI84 calculator and FALL and CLEAN in another. If this is not the case, download the programs. Short instruction on how to download here. Download IMPULSE to one calculator and FALL and CLEAN to another.
Connect the force sensor to the CBL unit in CH 1. Connect the CBL to the graphing calculator with the program IMPULSE. Connect the CBR to the other calculator.
The nose of the cart must be equipped with a collision protector, for example foam rubber. The back of the cart must have a reflector to give better reflections to the CBR. A part of the lid for a box of printer paper works fine.

It is convenient to use a table with a length of about one and a half meter for the experiment. The force sensor must be mounted firmly for example at the edge of the table, and its height adjusted so that the collision takes place as intended. Put the CBR behind the cart and about half a meter from the start position of the cart about one meter from the force probe.

- Start the program IMPULSE. Nothing will happen until there is a collision and data is pre-stored so the complete force-time graph will appear on the calculator screen when he experiment is done. Now you are ready to perform the experiment. Start the program FALL on the other calculator and immediately push the cart away towards the force sensor.
- When the experiment is done both calculator screens will show graphs. On one of them the y-axis shows the force acting on the force sensor in newtons and the x-axis the time in seconds. Force data are stored in list L_2 and time data in list L_1. The other calculator shows distance versus time for the cart. Lists L_1 through L_3 of this calculator contains time data, distance data and velocity data for the cart.
- View a movie showing the experiment.

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Data analysis (TI 83/TI84)

If you have any problems handling the graphing calculator help is available using the links that are underlined and highlighted in blue.

Analysis 1: Discussion of distance data

Study the graph and try to figure out what happens at different times during the motion. Explain the different slopes. What happens at the top of the graph?
As can be seen from the graph it is not quite linear. What does that mean? Can you find an explanation for this?
Use pairs of data points, one pair at each side of the top to calculate the velocity of the cart in the neighbourhood of the top. How big is the velocity change?
Calculate the momentum change of the cart.

Analysis 2: Discussion of velocity data

Next step is to graph the velocity (L3) as a function of time (L1).
Make statements concerning the graph. Compare all your statements from the previous section with the new ones. Do you find agreement between them?
Determine the velocity change during the collision and calculate the momentum change once more.
Compare the speeds immediately before and after the collision. Calculate the kinetic energies of the cart immediately before and after the collision. Is there an energy loss from the cart? Explain!

Analysis 3: Discussion of force data

Now look at the force acting at the force probe as a function of time. Does it look as you have expected? Is it possible to make any statements about the force acting on the cart?
The impulse on a body during an time interval Δt is defined as $I = F \cdot \Delta t$, where F is the force acting during this time.
Make calculations of the impulses on the cart during all time intervals. These calculations can be made for example in list L_3. To sum all these contributions to get the impulse on the cart during the collision you just use SUM L_3. The command SUM is found under LIST (2:nd STAT) MATH.

Analysis 4: Compare results from motion data and force data

In analysis 1 and 2 the momentum change of the cart has been calculated. In analysis 3 the impulse on the force sensor is calculated.
Now compare the momentum change of the cart with the impulse on the cart. Which is your conclusion.

When you have finished your work, but not before, you can compare your conclusions with this completed analysis.

Some extras to reflect upon

When the impulse was calculated we made a numerical integration to calculate the area between the force curve and the horizontal axis. What would have happened if the rubber foam have been stiffer or even taken away?
Explain why it is important that cars have airbags for collision protection.

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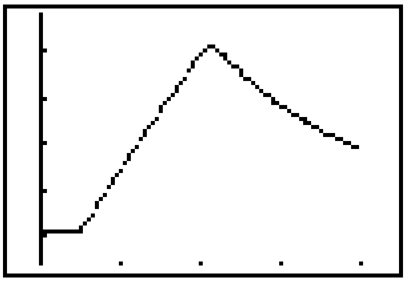
Complete analysis (TI83/TI84)

Completed analysis 1

The distance-time graph shows how the cart is standing still for a short while in the beginning. Then it is accelerated from the CBR during a short time interval between 0.4 s and 0,6 s, when it is pushed. After this the graph is almost linear until time 2.0 s where the rubber foam nose of the cart comes in contact with the force probe. This contact lasts about 0.2 s. After this the cart moves in the other direction back towards the CBR. This part of the graph is also almost linear.



If a distance-time graph is linear the motion is uniform, the velocity is constant. If you look at the graph once more both of the "almost linear parts" have changing slopes. In both cases there are velocity changes. The speed of the cart decreases in both. The reason for this is friction and air resistance. Another probable reason is that the table surface is not perfectly horizontal. If this is the case it can be seen, more about this later on.

L1	L2	L3 1
1.9567	1.1643	.46587
1.9967	1.1829	.46411
2.0366	1.2013	.43319
2.0765	1.2175	.27331
2.1164	1.2232	-.0018
2.1564	1.2174	-.2337
2.1963	1.2045	-.3231

L1(52) =2.07651

An excerpt from the table, time and distance, is shown here. Using the highlighted data point and the first data point shown give a possibility to calculate the velocity before the collision. If we repeat this with two points right after the collision we get the velocity after.
Before

$$v_1 = (1.2175-1.1643)/(2.0765-1.9567) \text{ m/s} \approx 0.444 \text{ m/s}.$$

After

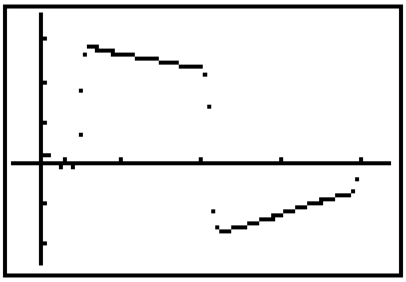
$$v_2 = (1.165\text{-}1.204)/(2.316\text{-}1.214)\ \text{m/s} \approx -0.334\ \text{m/s}.$$

The momentum change is

$$p = m(v_2 - v_1) = 1.060 \cdot (-0.334\text{-}0.445)\ \text{kgm/s} \approx -0.83\ \text{kgm/s}$$

Completed analysis 2

The velocity-time graph looks like this:



We recognize the short time interval between 0.4 s and 0.6 s when the cart is pushed away. After this we see the motion towards the force sensor. Some friction force is evidently present between 0.46 s and 2.0 s, giving the cart a reduced speed from 0.57 m/s to 0.46 m/s that is an average acceleration of (0.46-0.57)/(2.0-0.6) $m/s^2 \approx -0.079\ m/s^2$.

Then the cart collides reversing its direction of motion. Once more we can see that the motion back towards the CBR not is uniform. The graph is pretty linear with a slope giving the cart a decreased speed. Once more we can calculate the acceleration

$$a = (-0.15 - (-0.34)/(3.87 - 2.28)\ \text{m/s}^2 \approx 0.12\ \text{m/s}^2.$$

If we compare the absolute values of the two accelerations we see that the last one is considerably larger. Hence the force that reduces the speed is bigger and it seems as if there is a small incline of the table surface. Otherwise the two absolute values should have been approximately equal. Why does not the cart roll along the surface when left alone at rest?

If we take the velocities before and after the collision, 0.464 m/s and -0.339 m/s respectively, we can calculate the momentum change to

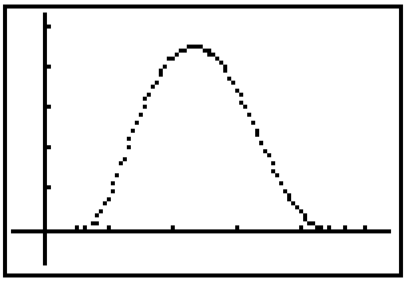
$$m(v_2 - v_1) = 1.060 \cdot (-0.339\text{-}0.464)\ \text{kgm/s} \approx -0.85\ \text{kgm/s}.$$

This value is in good agreement with the previous one, 0.83 kgm/s.

If we compare the speeds before, 0.464 m/s, and after, 0.339 m/s, we see that there is a loss of kinetic energy. How big? What proportion of the initial kinetic energy is lost?

The loss of kinetic energy is converted to heat in the force probe and in the rubber foam.

Completed analysis 3



The force versus time graph shows a pulse where the force grows to a maximum of 12 N and then decreases to zero again. The whole collision takes a little less than 0.2 s.
To calculate the impulse during one time interval simply multiply the force with the length of the interval, in our case 0.0025 s. Use list L_3 to do this. Position the cursor in the head of list L_3 and enter the formula $L_3 = 0.0025 * L_2$ and press ENTER. Finally sum all the values in list L_3. This can be done by going to the home screen (QUIT (2:nd MODE)) and The result is 0.898 Ns. Thus the impulse on the cart is –0.898 Ns ≈ 0.90 Ns.

Completed analysis 4

The momentum changes from analysis 1 and 2 are –0.83 kgm/s and 0.85 kgm/s respectively. These are in good agreement with the result that we cot from analysis 3 where the momentum was found to be 0.90 Ns.
Since the units seem different let us have a look at them.
$1 \text{ Ns} = 1 (\text{kg} \cdot \text{m/s}^2) \cdot \text{s} = 1 \text{ kgm/s}$.
The first step follows from the fact that force = mass times acceleration.
So our conclusion is that the impulse on the cart equals its momentum change. A theoretical derivation confirms this experimental result.