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Impulse and Momentum

The impulse-momentum theorem relates impulse, the average force applied to an object times the length of time the force is applied, and the change in momentum of the object:



Here we will only consider motion and forces along a single line. The average force,, is the *net* force on the object, but in the case where one force dominates all others it is sufficient to use only the large force in calculations and analysis.

For this experiment, a dynamics cart will roll along a level track. Its momentum will change as it reaches the end of an initially slack elastic tether cord, much like a horizontal bungee jump. The tether will stretch and apply an increasing force until the cart stops. The cart then changes direction and the tether will soon go slack. The force applied by the cord is measured by a Force Sensor. The cart velocity throughout the motion is measured with a Motion Detector. Using the calculator to find the average force during a time interval, you can test the impulse-momentum theorem.



Figure 1

objectives

* Measure a cart’s momentum change and compare to the impulse it receives.
* Calculate the work done on the cart by the elastic cord.

Materials

|  |  |
| --- | --- |
| CBL 2 interface | dynamics cart and track |
| TI Graphing Calculator | clamp |
| Vernier Force Sensor | elastic cord |
| Vernier Motion Detector  DataMate program | string  500-g mass |

Procedure

1. Measure the mass of your dynamics cart and record the value in the Data Table.
2. Place the track on a level surface. Confirm that the track is level by placing the low-friction cart on the track and releasing it from rest. It should not roll. If necessary, adjust the track.
3. Attach the elastic cord to the cart and then the cord to the force sensor. Choose a cord length so that the cart can roll freely with the cord slack for most of the track length, but be stopped by the cord before it reaches the end of the track. Clamp the Force Sensor so that the cord, when taut, is horizontal and in line with the cart’s motion.
4. Place the Motion Detector beyond the other end of the track so that the detector has a clear view of the cart’s motion along the entire track length. When the cord is stretched to maximum extension the cart should not be closer than 0.4 m to the detector.
5. Connect the Student Force Sensor to Channel 1 of the CBL 2 interface. Connect the Motion Detector to the SONIC/DIG or SONIC/DIG 1 input of the interface. Use the black link cable to connect the interface to the TI Graphing Calculator. Firmly press in the cable ends.
6. Turn on the calculator and start the DATAMATE program. Press  to reset the program.

7. If CH 1 displays the Force Sensor and its current reading, skip the remainder of this step. If not, set up DATAMATE for the Force Sensor manually (the interface will recognize the Motion Detector automatically). To do this,

1. Select SETUP from the main screen.
2. Press  to select CH1
3. Choose FORCE from the SELECT SENSOR list.
4. Choose STUDENT FORCE for your force sensor.
5. Select OK to return to the main screen.

8. Zero the Force Sensor.

1. Select SETUP from the main screen.
2. Select ZERO.
3. Select CH 1 from the SELECT CHANNEL menu.
4. Remove all force from the Force Sensor.
5. When the reading on the calculator screen is stable, press  to record the zero condition.

9. Set up the calculator and interface for data collection.

1. Select SETUP from the main screen.
2. Press  to select MODE and press .
3. Select TIME GRAPH from the SELECT MODE screen.
4. Select CHANGE TIME SETTINGS.
5. Enter “0.02” as the time between samples in seconds. (Use “0.05” for the TI-73 and 83.)
6. Enter “150” as the number of samples. (Use “50” for the TI-73 and 83.)
7. Select OK twice to return to the main screen.

10. Practice releasing the cart so it rolls toward the Motion Detector, bounces gently, and returns to your hand. The Force Sensor must not shift and the cart must stay on the track. Arrange the cord and string so that when they are slack they do not interfere with the cart motion. You may need to guide the string by hand, but be sure that you do not apply any force to the cart or Force Sensor. Keep your hands away from between the cart and the Motion Detector.

11. Select START to take data. As soon as you hear the interface beep, roll the cart as you practiced in the previous step.

12. Study your graphs to determine if the run was useful:

1. Press  to see the force graph.
2. Inspect the force data. If the peak is flattened, then the applied force is too large. Repeat your data collection with a lower initial speed.
3. Press  to return to the graph selection screen.
4. Press  to select DIG-DISTANCE.
5. Press  to see the distance graph.
6. Confirm that the Motion Detector detected the cart throughout its travel. If there is a noisy or flat spot near the time of closest approach, then the Motion Detector was too close to the cart. Move the Motion Detector away from the cart, and repeat your data collection.
7. Press  to return to the graph selection screen, and select MAIN SCREEN.
8. To collect further data, return to Step 11.

13. Once you have made a run with good distance and force graphs, analyze your data. To test the impulse-momentum theorem, you need the velocity before and after the impulse. To find these values,

1. Select ANALYZE from the main screen.
2. Select STATISTICS from the ANALYZE OPTIONS.
3. Select DIG-VELOCITY from the SELECT GRAPH screen.
4. Now you can select a portion of the velocity graph for averaging. Using the  and  cursor keys, move the lower bound cursor to the left side of the approximately constant- and negative-velocity region. Press .
5. Now set the upper bound: Move the cursor to the right edge of the approximately constant- and negative-velocity region. Press .
6. Read the average velocity before the collision (*vi*) from the calculator. Record the value in your Data Table.
7. Press  to return to the ANALYZE OPTIONS screen.
8. In the same manner, determine the average velocity just after the bounce (*vf*) and record this positive value in your Data Table.

14. (Calculus version) Now record the value of the impulse.

1. Select INTEGRAL from the ANALYZE OPTIONS.
2. Select CH1-FORCE(N) from the select graph screen.
3. Now you can select a portion of the force graph for integration. Using the cursor keys, move the cursor to just before the impulse begins, where the force becomes non-zero. Press .
4. Now move the cursor to the right edge of the impulse, where the force returns to zero. Press .
5. Calculus tells us that the expression for the impulse is equivalent to the integral of the force *vs.* time graph, or

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Read the value of the integral, the impulse, from the calculator, and record the value in your Data Table.

1. Press  to return to the ANALYSIS OPTIONS screen.
2. Select RETURN TO MAIN SCREEN.

15. Perform a second trial by repeating Steps 11 – 14, and record the information in your Data Table.

16. Calculate the work.  
Upload the force and displacement data to LoggerPro and create a graph of F vs. x. Use the LoggerPro integral function to find the area under the curve and record in the work column of the data table in the trial 2 row. You will not calculate the work for trial 1.

Data Table

|  |  |
| --- | --- |
| Mass of cart | 0.2537 kg |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Trial | Avg. Final Velocity *vf* (m/s) | Avg. Initial Velocity *vi*(m/s) | Change of Velocity  (m/s) | Change in momentum (kg m/s) | Impulse *F*Δ*t* (N⋅s) | % difference between Impulse and Change in momentum |
| 1 | 1.179 | -1.299 | 2.478 | 0.6287 | 0.522 | 18.55% |
| 2 |  |  |  |  |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
| Trial | Work  (J) | Change in Kinetic Energy (J) | % difference between work and change in kinetic energy |
| 1 | N/A | -0.03772 | N/A |

DATA Analysis

1. Calculate the change in velocities and record in the Data Table. From the mass of the cart and change in velocity, determine the change in momentum as a result of the impulse. Make this calculation for each trial and enter the values in the Data Table.
2. If the impulse-momentum theorem is correct, the change in momentum will equal the impulse for each trial. Experimental measurement errors, along with friction and shifting of the track or Force Sensor, will keep the two from being exactly the same. One way to compare the two is to find their percentage difference. Divide the difference between the two values by the average of the two, and then multiply by 100%. How close are your values, percentage-wise? Do your data support the impulse-momentum theorem?
3. Find the change in kinetic energy before and after the impulse and record in the data table. Determine the percent difference between work and change in kinetic energy. Do your data support the work-energy theorem?

conclusion

The cart’s calculated change in momentum and the impulse found from the graph of the force vs. time curve were not the same. The impulse-momentum theory states that these values should be equal; however, due to error in the lab, this theory is unable to be proven. The 18.55% error was discovered to be caused by a default in the force sensor used, after all measurements were taken and values calculated. This error caused the graph of the data to begin below the x-axis, and therefore incorrectly calculate the integral of the curve. Another source of error that was discovered after the experiment was that the track was not level, and therefore the cart moved toward one end when no experimenter force was added.

For this experiment, the work was not calculated due to graphical reasons; however, the change in kinetic energy was calculated. In an ideal situation, the change in kinetic energy, and therefore work, should be zero, because the final and initial velocities should be the same. The slight change that was found was due to some error, likely the error caused by the slight incline of the track as well as friction.