Inertial Balance

P4-1050

BACKGROUND:

Mass is the quantity of matter in a body. Particularly, it is a measure of the inertia or "laziness" that a body exhibits in response to any effort made to start it, stop it or change in any way its state of motion. An inertial balance is a spring device that vibrates the body in order to change the velocity and record this "laziness". Inertial mass is measured as a dynamic measurement, unlike gravitational mass, which is measured as a static measurement.

This inertia balance kit is primarily designed for use in a laboratory experiment, in which mass is quantitatively measured independent of the Earth's gravitational force to demonstrate Newton's First Law. This same method is often used in space flights to determine the mass of an object under weightless conditions. The kit includes a frame with two platforms (one with holes) connected by two, horizontal spring blades. Also included are three cylinders of unknown mass with shoulders, each can be placed in the holes in the platform. One of these masses has a hole to allow it to be suspended by string (included) from a ring stand (not included) or other device.

SAFTY PRECAUTIONS:

Be careful handling the balance, the spring blades are very sharp!

Make sure to securely attach the C-Clamp to a well-braced bench or table so that the platform does not move. If C-Clamp is not securely attached to the platform, the apparatus may fall or move during operation, producing undesirable results.

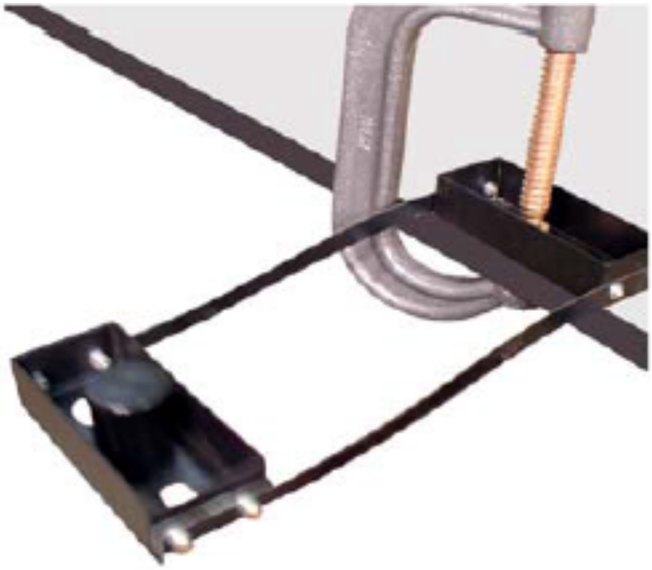
When the spring blades are in motion, the cylinder(s) may become dislodged from their hole(s) and fall or fly out of the platform. Make sure the area is clear before beginning experiment. Keep feet clear from the area under the platform.

Be careful not to overextend the spring blades. Do not bend to one side more then approximately 2 inches. Over bending may cause cylinders to become dislodged when the platform is released.

PART 1:

DETERMINING THE MASS OF AN UNKNOWN LOAD

1. Securely clamp the inertia balance to a well-braced bench or table using a C-Clamp that is clamped to the platform that doesn't have holes drilled in it (see image below). The platform with the holes will be used for supporting the load.



2. Use a double pan, triple beam balance or digital scale to find the gravitational masses of each of the three included cylindrical masses. They should each be roughly 300 grams. It may be helpful to number each mass and record its gravitational mass for future reference.

3. Place one cylindrical mass in the center hole of the platform. Set the balance in a side to side motion, by bending the platform to one side approximately 2" (or less) and releasing. Get synchronized with the motion of the balance before starting the stopwatch. (By waiting until several oscillations have occurred before starting the stopwatch, there should be no slippage of the masses in the platform.) Start the stopwatch on the count of "zero" and either count how many complete vibrations occur in a given time period(10, 20, 30 seconds, for example) or determine the time for a given number of vibrations (at least 40 or 50). Use which ever method works best for you and your curriculum. Perform one of the selected procedures three times and average the results.

4. Repeat step #3 using two cylinders, positioning them in the right and the left holes of the platform. Again, be sure to conduct three trials for a given number of vibrations (or time) and determine the average.
5. Without removing the two cylinders, place the third cylinder in the middle hole and repeat step #3, conducting three trials using the same number of vibrations (or time).
6. (optional) More data points could be created by using additional weights of known mass.

7. Create a data table to record all of your data. The table should look similar to the one below:

Mass	Vibrations	Cycles per Second	Period	Period Squared
0	50	5	0.2	0.04
300	28	2.8	0.3571	0.12755102
600	22	2.2	0.4545	0.20661157
900	18	1.8	0.5556	0.308641975

8. G h these results on two separate graphs, one for Mass vs. Period (T) and one for Mass vs. T^2. Mass will lie on the x-axis.

9. These graphs can now be used as “calibration graphs” for the inertial balance. Place a weight of unknown mass onto the inertial balance and perform the same timing procedure that was used in step 1. Take the period from this new unknown mass to the calibration graph to determine its inertial mass. Use a traditional balance to verify the results. This procedure can be preformed for any number of masses, just be sure to not exceed the capacity of the inertial balance (about 1.5kg). Note that it may also be necessary to tape the unknown masses down in the tray to make sure they do not move during testing.

   NOTE: When performing all of these trials, it’s important to measure either the period or frequency throughout the entire experiment – not both, in order to generate accurate results. Also, do not try to time one period, or determine the number of vibrations in one second! Record the time for 20 or 30 (or so) vibrations, or the number of vibrations in 20 or 30 seconds (or so).

PART 2: ADVANCED

Determining the spring constant for the inertial balance. The inertial balance is a compound spring system for which the period can be defined as:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Where “T” is the period, “m” is the mass on the spring and “k” is the spring constant. Solve this for “T^2” and the equation becomes:

$$T^2 = 4\pi^2\left(\frac{m}{k}\right) \qquad \text{or} \qquad T^2 = \left(\frac{4\pi^2}{k}\right)m$$

Rearranged again, for “k”

$$k = \left(\frac{4\pi^2}{T^2}\right)m$$

At this point, the coefficient “m” can be set to the slope of the graph. This can be either be done by using Excel to graph the data points and adding a Trend line, or by the tried and true *y=mx + b* equation. The value for “k” can then be determined from the above equation.

PART 3:

DETERMINING THE MASS OF AN UNKNOWN MASS NOT SUPPORTED BY THE PLATFORM

1. Following step #2 in **Part 1**, determine the time for a given number of vibrations for the cylinder with the hole drilled all the way through it.

2. Feed a string (included) through the hole in the cylindrical mass. Set up a ring stand or other support rod and suspend the mass in the center hole of the inertia balance. The string should be vertical. The mass should be free to vibrate but the inertia balance should not be supporting the weight. Determine the time for a given number of vibrations. Again, you can also determine the time it takes for a certain number of complete vibrations (over and back) to occur.

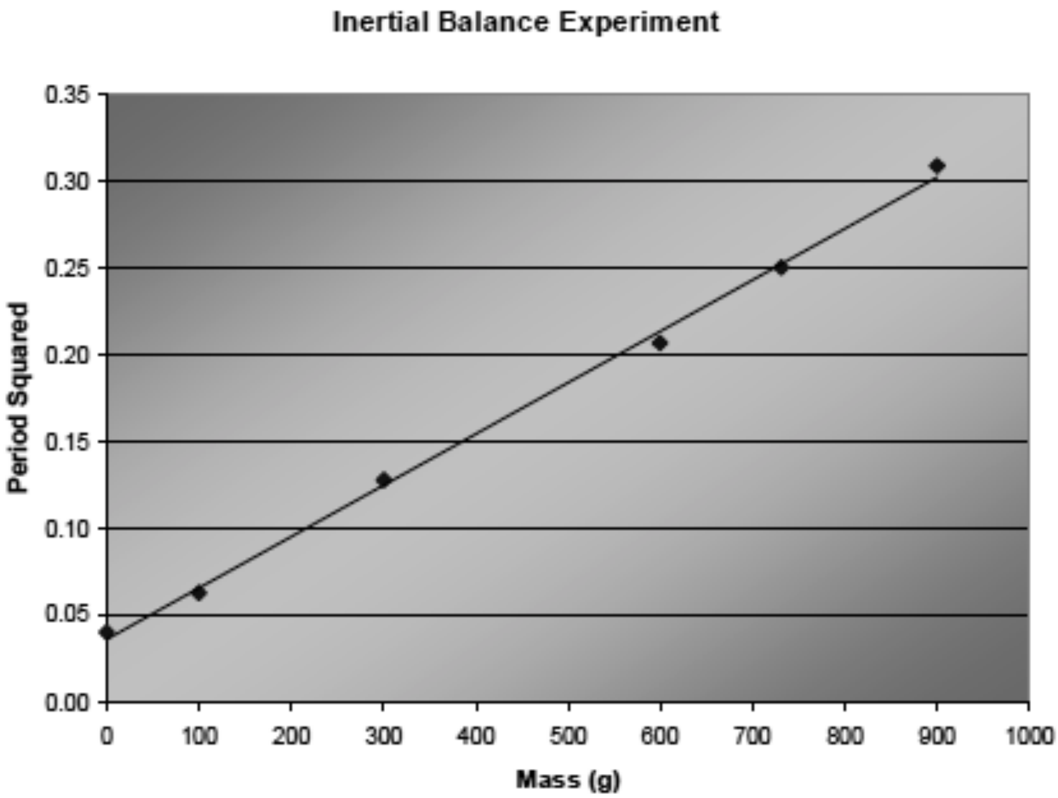
3. Compare the period from the suspended mass with that of the unsuspended one.

4. Note that the oscillations do not depend on gravity, but rather just on mass:

$$T \propto \sqrt{m}$$

RESULTS:

Example Graph from Data table: (note extra data points from additional masses)



ADDITIONAL ACTIVITIES:

1. What are some advantages of timing 20 vibrations of the inertial balance instead of just one?
2. Are the inertial mass and gravitational mass the same? What is the ratio? How is this explained?
3. What would be your gravitational mass be on the moon? (Gravity on the moon is 1/6 of the gravity on the earth). What would it be on Jupiter? (2.37 times that of the earth)
4. What is the difference between inertial mass and gravitational mass?
5. How would gravitational mass and inertial mass change in an elevator (if at all)? Why is this true?
6. How accurately do you think the inertial balance measured the masses of your unknowns? What limits your accuracy?
7. Which is a more common way of measuring mass on Earth, a triple beam balance or an inertial balance?
8. Would the inertial balance successfully measure mass in the Space Shuttle when it is in orbit around the earth?
9. Standard optional questions may be asked, such as “What are sources of error”, “Determine percent error”, etc.

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