Experiments from Interactive Physics Laboratory – rotating systems

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This article describes four experiments that belong to the field of rotating systems, one of the topics with which students could meet during their visits to Interactive Physics Laboratory (http://kdf.mff.cuni.cz/ifl/) at the Faculty of Mathematics and Physics of Charles University in Prague (MFF UK) in the school year 2013/2014. We will also briefly describe a working principle of the laboratory.

Concept of the laboratory

Interactive Physics Laboratory (hereinafter IPL) was established by MFF UK. The laboratory is also used for teaching students, who study Physics Directed Towards Education at MFF. However, it is primarily meant for secondary school students. They have an opportunity to try a number of experiments, which are directly related to the topics they learn at school or which expand on them. Everything takes place as practical exercises, during which students work in teams. For each team (max. 6 members) two hours of time are reserved. There are always four different stands prepared, which fall into one thematic unit. In case of some topics, experiments are more complicated and time-consuming. In that case, one team of max. 4 students spends all the time at one stand. An important part in such a situation are final presentations of the teams. Students have to sum up for others what they were doing during the time spent in the laboratory and what results they have obtained. However, in IPL we offer easier, or, more precisely, not so time-consuming experiments too. In this case, all the activities are arranged in the way, so that every team passes all the stands. Even in this situation, we pay attention to closing presentations, which now play a role of final revision. Then students also have an opportunity to compare their results with the results of their colleagues.

More information about the laboratory's functioning, description of thematic units, contact and procedure for registration with students can be found on the IPL's website [1].

Experiments in rotating systems

This article further deals with description of one of the experimental units, which we offer in IPL. It is about experiments whose common denominator is rotational motion. Experiments are short and less difficult. Thus, students can try all the experiments.

Centripetal force

The following two experimental tasks have been chosen for the topic about centripetal force:

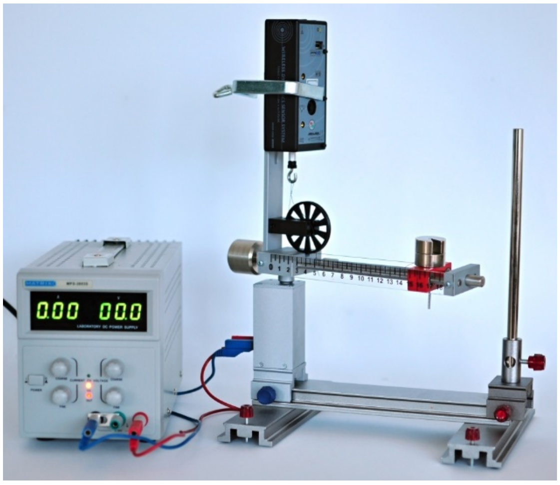
1. Verify the dependence of centripetal force's magnitude on rotation period.
2. Using the equation for centripetal force, determine the mass of the unknown body in rotating system.

This topic is commonly learnt in secondary schools and students already know the equation

$$F_d = 4\pi^2 mr \cdot \frac{1}{T^2} \quad (1)$$

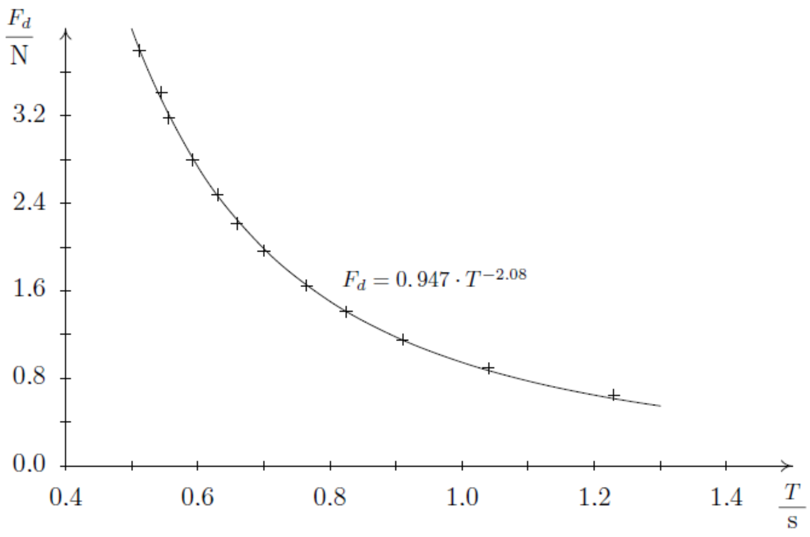
which defines the dependence of the magnitude of centripetal force F_d on the body's mass m, on the radius of rotation r and on the rotation period T.

For this measurement in IPL, we use an original apparatus for measuring magnitude of centripetal force (picture 1) from the NTL company. The apparatus comprises of a swivel arm, which is powered by an electric motor. On the arm, there is a moveable runner, which can be attached to a dynamometer using a low friction pulley. The setup also includes two weights of fifty grams, an adjustable alternating voltage source, stop-watch and a Vernier wireless dynamometer, which is connected to computer. This way students record data from the dynamometer and add values measured with stop-watch.



Picture 1

The result of students' effort is the obtained dependence, which is shown, for example, in the graph in picture 2. As you see, the curve passing through the measured points well fits the expected dependence.



Picture 2. Graph of dependence of centripetal force's magnitude on magnitude of rotation period.

Then students will compare the equation that they have obtained after connecting the measured points with the equation (1) given by theory. After that, knowing the radius of the body's rotation (r = 15.7 cm), they will calculate the mass of the body on which centripetal force has been acting.

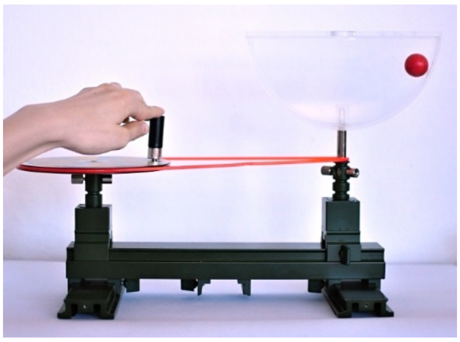
$$4\pi^2 mr \cdot T^{-2} \doteq 0.947 \cdot T^{-2.08}$$

$$m \doteq \frac{0.947}{4\pi^2 \cdot 0.157}\ \mathrm{kg} \doteq 153\ \mathrm{g}$$

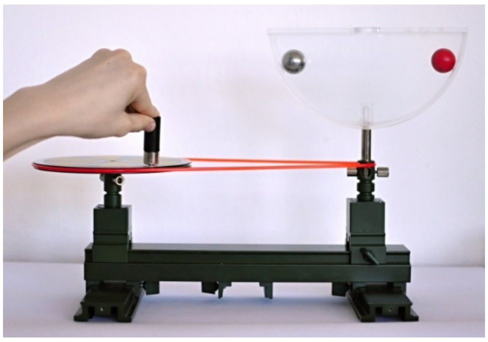
This figure very well corresponds to the real value, which is 150 g.

Balls in a cuvette

The second stand, which students will visit in IPL under the topic of rotational motion, first aims at their ability to estimate the result and ability to apply knowledge that they learnt in school in a simple practical situation. At first, only one ball (red plastic one) is put into the cuvette. Students will try what happens if they spin the cuvette (picture 3). Then they will get the task to put another ball (steel) into the same cuvette, after which they are asked, at what height the balls will stabilize in case of constant rotational speed, or rather which one will be higher. This question is very difficult for students and they are often surprised with the solution (picture 4).



Picture 3



Picture 4

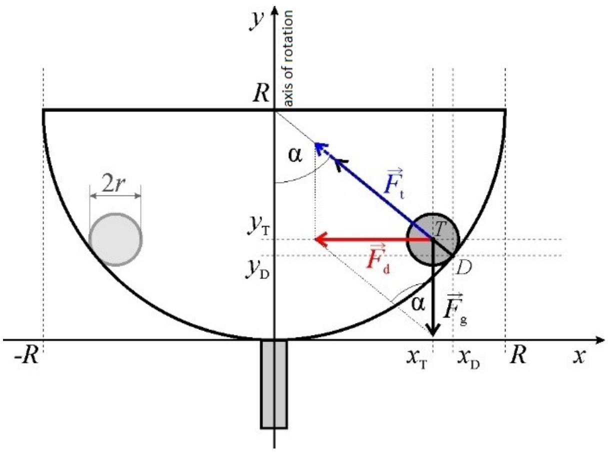
$$\tan\alpha = \frac{F_d}{F_g} = \frac{m\omega^2 x_T}{mg}$$

$$\tan\alpha = \frac{\omega^2 x_T}{g}$$

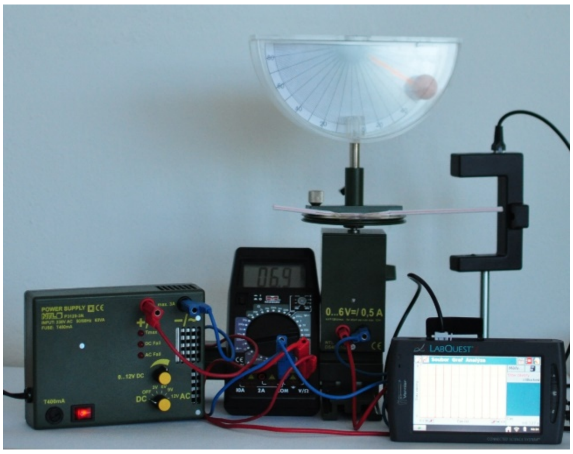
$$\tan\alpha = \frac{4\pi^2}{g}\cdot\frac{x_T}{T^2} \quad (2)$$

Then, the experiment worksheet will provide them with theoretical deriving of the conclusion that they have seen in the mentioned experiment, which means that the ball's location in the cuvette does not depend on its mass (equation (2), picture 5).

Final experiment of this section is quantitative and it verifies the dependence $\alpha(T)$ derived by students. At this part students will rebuild the set, so that the cuvette would not be driven manually but by an electric motor (picture 6). To one side of the cuvette students will attach a protractor on which they will mark out the position (angle), at which the ball is stabilized.



Picture 5

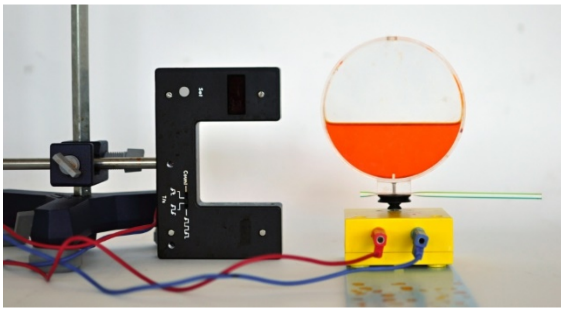


Picture 6

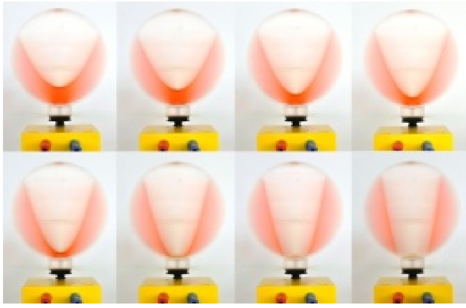
Then they increase the voltage connected with the motor, thereby the frequency of rotation and the ball rise. After substituting marked position, students will measure the length of the rotation period using an optical sensor connected to the data logger. This measurement comes off surprisingly accurately. In case of calculating the angle from the measured period, relative deviations range around 1-2 %.

Liquid in a rotating vessel

At the next stand students determine the shape of a surface in the rotating vessel. One of the possible ways of this determination has been already described in the article [2] by me and doc. L. Dvořák. Students work with the set (picture 7) that comprises of a cuvette connected to an electric motor, which is connected to an adjustable voltage source. Cuvette is full of water coloured with a food dye.



Picture 7

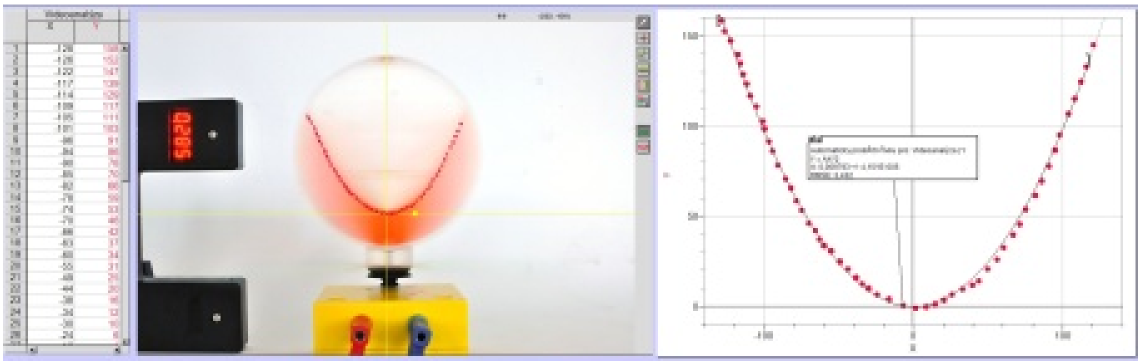


Picture 8

Even before the actual experiment students are asked to guess the surface shape. The majority of students is close to the correct solution, nevertheless, a number of wrong guesses turns up too.

At first, students will study the shape of the surface qualitatively. They increase the motor's velocity and observe, how the surface shape changes. Shapes of the surface at different velocities, which are being gradually increased, have been photographed and pictures of them are in picture 8.

Then students will choose the one rotation period and take a long-exposure (ca. 5 s) photograph of the surface. After that the experiment worksheet will provide students with analysis of the taken photo of the curved surface's shape. Analysis takes place in the program Logger Pro. Students will select some points on the surface, which will be plotted on a Cartesian coordinate system by the program. Then they will let the program to plot a curve satisfying the condition of power function, which passes through the selected points. The situation is captured in picture 9.



Picture 9

Through the further discussion about the dependence on other possible quantities and with a little help from lectors and the worksheet, students get the equation for the surface's shape in a rotating vessel

$$h = \frac{\omega^2}{2g} R,$$

where h is height of a certain point of the surface above its lowest point, ω is angular velocity of the liquid's rotation and R is distance between the selected point of the surface from the axis of rotation.

Behaviour of a boat on the rotating surface

The main aim of the last stand is to demonstrate, how a small body behaves on the curved surface of a rotating liquid. This problem is presented to students in connection with a poem "A Descent into the Maelstrom" by E. A. Poe, in which the main character is thinking, how to escape from the massive whirlpool and notice that some bodies are pulled up, while some others go down.

At first, students have to study different types of whirls: whirlpool created in a bottle (typical experiment, for example see [3]) and fire whirl (picture 10). The set for a fire whirl consists of a swivel food tray, on which has been attached a wire basket with a metal bowl on the bottom. Afterwards, we will pour denatured alcohol into the bowl and light it with a wood skewer. If we spin the set, the fire whirls will be created. As long as the bowl of the burning alcohol is not put into the basket, despite its rotational motion the fire whirl will not arise.

Picture 10: Fire in the non-rotating basket. Fire on the rotating tray. Fire on the rotating tray in the basket.

As we have mentioned before, in the second part students study motion of the bodies on the rotating surface and try to find general rules which influence this motion, like which bodies rise up, which ones conversely "fall" down to the paraboloid's axis. I have described this experiment in more detail in articles [2] and [4].

References

[1] http://kdf.mff.cuni.cz/ifl [cit. 27.8.2014]

[2] Šabatka, Z.; Dvořák, L. Vodní paraboloid. In Dvořák L. (ed.) *Veletrh nápadů učitelů fyziky 12, sborník z konference*. Prometheus Praha 2007. s. 197-201. ISBN 978-80-7196-352-3. Available on: http://vnuf.cz/sbornik/prispevky/12-20-Sabatka.html. [cit. 27.8.2014]

[3] Ondrušek, V. Pokusy s jednoduchými pomůckami. In *Veletrh nápadů učitelů fyziky 2, sborník z konference.* Plzeň 1997. Available on: http://vnuf.cz/sbornik/prispevky/02-17-Ondrusek.html. [cit. 27.8.2014]

[4] Šabatka, Z., Dvořák, L. Simple verification of the parabolic shape of a rotating liquid and a boat on its surface 2010 *Physics Education* **45** 462-8.