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LETTERS AND COMMENTS

Multimedia in physics education: a video for the quantitative analysis of the centrifugal force and the Coriolis force

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Abstract

A digital video on forces occurring in rotating frames of reference is presented. It allows students to observe and to analyse the trajectory of one and the same moving ball in both systems, the laboratory system at rest and the rotating system. An application of the video for physics exercises in the first year of physics study is outlined.

(Some figures in this article are in colour only in the electronic version)

The topic around the Coriolis force (such as linearly accelerated and rotating frames of reference, inertial reference frames, fictitious or inertial forces) plays a major role in teaching mechanics. The phenomenon itself occurs in nature, in technical applications as well as in everyday life.

But as experience tells us, learners do have difficulties in general to understand this concept (here transformation of coordinates): one reason could be that the demonstration experiments in class are unclear (e.g. Foucault pendulum); another reason could be that static representations in physics books are misleading or simply wrong; or that text books sometimes persuade the reader that fictitious forces are not really existing/acting forces. In addition, the observer (pupil or student), watching such a demonstration experiment, is located in the coordinate system at rest (laboratory system), whereas the Coriolis force acts and can be visualized only in the accelerated coordinate system. Several ‘tricks’ are known in specially designed demonstration experiments to visualize the Coriolis force, such as a pendulum filled with sand over a rotating disc or monitoring the trajectory of a rolling ball over a rotating disc [1]. But all those tricks require the skill of a learner to perform the transformation of the two reference frames (at rest and accelerated) quasi in their mind. As teaching media we know of many convincing videos (e.g. carousel, winds around a low pressure area in the Northern/Southern Hemisphere). Common to all of them, the observer is located either in the rotating system or in the system at rest. Technical advantages of digital videos are not

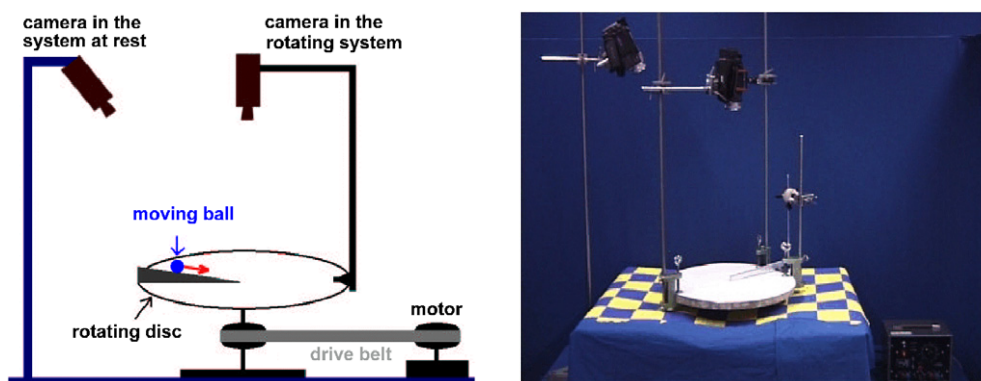


Figure 1. Experimental set-up (left: scheme; right: photo).

used [2]. On the other hand, since this topic is a challenge in physics teaching efforts have been undertaken in the past to illustrate phenomena related to different reference frames; we would like to refer here to the legendary film *Frames of Reference* by Hume and Ivey from 1960 [3].

As is well known, the Coriolis force becomes noticeable on a body, for example, if the body is moving radial with constant velocity in a constantly rotating system (i.e., this system is accelerated). From the view of the laboratory system at rest, this body is moving without forces acting on it; therefore its trajectory of motion is a straight line (if we neglect friction). From the view of the accelerated coordinate system, the trajectory of this body will deviate from a straight line as a consequence of the additional force acting on that body. Therefore one has to monitor one and the same motion of a body from the view of these two coordinate systems (at rest and accelerated), to demonstrate clearly the difference. This is exactly the approach of our video to realize these two ‘views’.

The experimental set-up is shown in figure 1: a digital camera, fixed to the floor of the laboratory, shows the view of the coordinate system at rest; a further camera, fixed on the rotating disc, shows the view of the accelerated coordinate system. The difference in both views is very obvious in our video, because the noticeable pattern of the lab table is at rest or rotating. The rest of the experimental set-up is known: the ball is rolling down an inclined plane; in the middle of the disc the ball leaves the inclined plane; then the ball is rolling with a constant radial velocity (Newton’s first law: $F = 0 \Leftrightarrow v = \text{const}$ applied to the system at rest). A motor is rotating the disc with constant frequency.

The result is shown in figure 2. One and the same trajectory of a rolling ball is viewed by the video camera at rest (left part) or viewed by the rotating video camera (right part). The video camera is taking 25 pictures per second; therefore one can mark the position of the ball in the trajectory by equidistant points for visualization.

We are producing our teaching videos in such a way that the observer can simply watch the video (qualitative approach) or during looking at the video the observer can perform measurements (quantitative approach). These activities—to measure and analyse data (see figure 3 and in the appendix)—are related to a specific problem, of course.

All necessary data/information (such as radius of disc, frequency of rotating disc, position of ball at given times) are available with this video. Therefore, the observer of this video can experimentally check the theoretical definition of the Coriolis acceleration.

This video—Coriolis and centrifugal forces—can be downloaded for free with average resolution [4] or can be ordered from the authors on CD-ROM with higher quality [5].

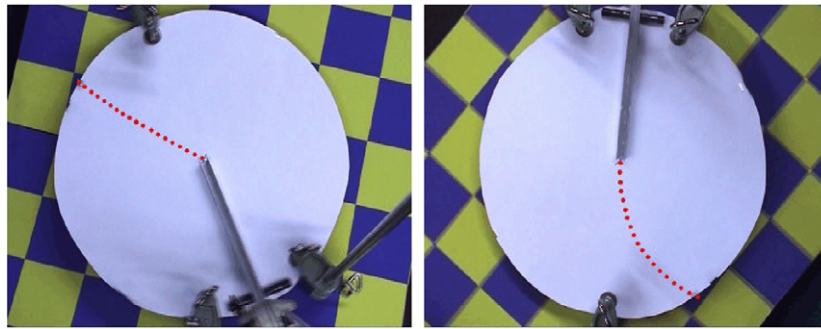


Figure 2. Result of marked trajectory of one and the same motion (left: view in the lab system at rest, right: view in the accelerated system).

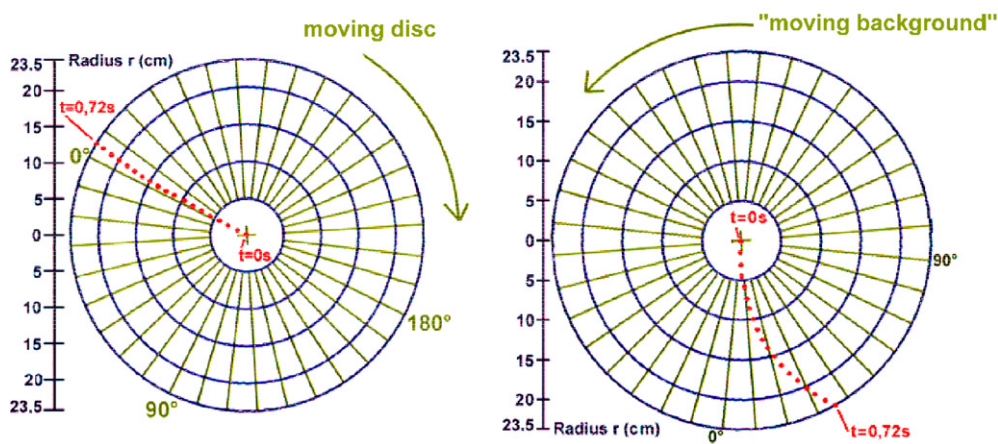


Figure 3. Analysis of the motion (figure 2) by means of a polar diagram (coordinates radius r and angle ϕ).

Appendix

The following problem was assigned several times in exercises for physics beginners in the first semester at university. The solution can be obtained by contacting the authors.

Problem

While the forces occurring in linearly accelerated frames of reference (e.g. in a lift) can be easily understood, the forces occurring in rotating systems (such as the earth) are much more difficult to understand. The term ‘fictitious’ may lead to the misunderstanding that such forces are not real. On the other hand, our body can experience those forces when, for example, we are moving in bus driving on a bendy road.

The video ‘Coriolis and centrifugal forces’ shows one and the same motion of a rolling ball on a rotating disc; from that one can easily conclude that it is necessary to introduce additional accelerations in the rotating system to describe the motion of the ball. This ‘fictitious’

acceleration has to be put down to the accelerated motion of the disc, since circular motion is an accelerated one.

Rotating frame of reference



Your task. First, calculate the velocity \vec{v}' and the acceleration \vec{a}' for a moving mass in the rotating system (general). Then, determine from the data given by the video the acceleration $\vec{a}' = (a'_r, a'_\varphi, a'_z)$ and $|\vec{a}'|$ of the ball when it is arriving at the border of the rotating disc.

Comments. Use cylinder coordinates (r, φ, z) for the calculation. Neglect the small friction of the ball's trajectory in the system at rest. Make use of the angular velocity $\vec{\omega} = (0, 0, -\omega)$ for the rotating disc.

References

- [1] Meiners H F (ed) 1970 *Physics Demonstration Experiments* (New York: The Ronald Press Company)
- [2] We mention here only a few examples for illustration:
 - Forces and Winds—Online Meteorology Guide* (Champaign, IL: University of Illinois Press) [http://ww2010.atmos.uiuc.edu/\(Gh\)/guides/mtr/fw/crls.rxml](http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/fw/crls.rxml)
 - The Video Encyclopedia of Physics Demonstrations* (Los Angeles: The Education Group) <http://dvd.physicsdemos.com/en/pdf/600Demoen.pdf>; <http://www.physicsdemos.com/>
 - Physical Oceanography Demo Movies* (Kingston, RI: Graduate School for Oceanography, University of Rhode Island) <http://www.po.gso.uri.edu/demos/>
 - Marshall J *Physics of Atmospheres and Oceans—Course 12.003* (Cambridge, MA: Massachusetts Institute of Technology) <http://www-paoc.mit.edu/labweb/lab5/gfd.v.htm>;
 - Physics and Astronomy Lecture Demonstrations: Coriolis Effect—IE30.28* (Iowa City, IO: University of Iowa) <http://faraday.physics.uiowa.edu/mech/IE30.28.htm>
- [3] Brown F L 1963 *Frames of Reference* PSSC film and excerpts I and II from it *Am. J. Phys.* **31** 400–1
- Steyn-Ross A and Ivey D G 1992 *Frames of Reference* revisited *Am. J. Phys.* **60** 1069–85 <http://www.ztek.com/>
- [4] File size ca 19 MB, for Real Player, http://pen.physik.uni-kl.de/medien/MM_Videos/index_eng.html
- [5] File size ca 100 MB, avi format, reimbursement of expenses 5.- euro