A simple velocity visualisation on a dynamics track

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Nowadays, ultrasonic or rotary motion sensors are mostly used in school experiments to monitor kinematical quantities (position, velocity and acceleration) of moving objects. Especially the ultrasonic sensors are fast and easy to operate; the rotary motion sensors require more or less a carefull preparation of the experiment. Both types of sensors can provide the absolute values of kinematical quantities. On the other hand, these sensors must be attached to a computer with a larger display or a digital projector in order to observe their values in class experiments. Simpler and more intuitive alternative methods are still worth using in teacher's demonstrations, in which precise measurement of kinematical quantities is not needed. In previous work [1], we described a photoluminescent technique for visualisation of a trajectory of a Blackburn pendulum. In this work we use this technique to visualise velocities of carts moving on a dynamics track.

A set-up of such experiment is shown in figure 1. A standard dynamics track (from Pasco Scientific [3]) is enhanced with a photoluminescent strip, fixed permanently above and slightly behind the track. The strip is made of a phosphorescent material commonly used in photoluminescent safety signs [1]. Carts on the track are equipped with self-made superstructures containing a laser pointer, a simple electronics and batteries. The laser pointers (violet wavelength 405 nm, light power 5 mW, class 3R) shine on the strip and excite the luminescent material in regions determined by cart positions. Small lenses with short focal length ($f = 8\,\mathrm{mm}$) mounted permanently on the laser outputs focuse the laser beams onto the photoluminescent strip. Moreover, producing strongly divergent beams at distances larger than f they also enhance the safety of the experiment. Since the lasers are placed on the carts at different heights, their luminescent traces do not overlap on the strip. The laser pointers are supplied directly from the output of employed NE 555 integrated circuits [2]. Working in an astable mode, the circuits generate rectangular voltage pulses switching on and off the laser pointers periodically. A frequency and a duty cycle of voltage pulses can be set by an adjustable resistor connected to the integrated circuit. These values must be matched on both carts, e.g. by comparing the waveforms of photocurrent from solar cells illuminated by flashing lasers. The frequency $f = 6\,\mathrm{Hz}$ and the duty cycle $D \approx 60\,\%$ are suitable for all described experiments. When the carts move on the track, flashing lasers draw glowing abscissae on the luminescent strip with length proportional to the cart velocity. Due to a slow phosphorescence of the photoluminescent material, the abscissae are clearly visible in a slightly shaded room within several minutes after the exposure. The carts with superstructures have equal masses. Additional mass, which can double the total mass of the cart with the superstructure, can be loaded under the cart superstructure.

Examples of velocity visualisation in typical experiments on the dynamics track [3] are shown in figure 2. The images were taken during or just after the experiment. An almost uniform motion of a single cart on a smooth horizontal track, a decelerated motion on a track covered with a soft foil and an accelerated motion down an incline are recorded in figure 2 (a) – (c), respectively. Whilst the glowing abscissae proportional to the velocities are nearly of the same length in figure (a), they are gradually shortening from left to right in image (b) and elongating in image (c).

Experiments demonstrating a conservation of momentum of two-cart system are documented by figures 2 (d) – (g). A complete momentum transfer between carts having the same masses is shown in figure 2 (d). While the cart A has stopped after the collision, the cart B is moving, drawing abscissae of the same length. fg:examples (e) displays the same experiment with carts with unequal masses ($m_\mathrm{A} : m_\mathrm{B} = 2$). Since the velocity of cart A is decreased considerably in the collision (theoretical

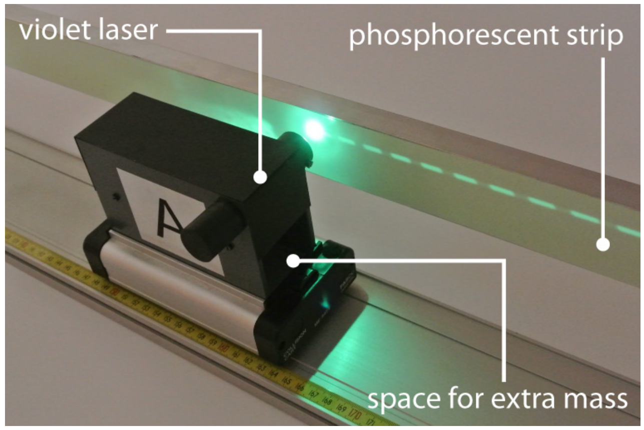

Figure 1: Experimental set-up. Violet laser pointer, fixed in a cart superstructure, draws glowing abscissae on a green phosphorescent strip.

value is $v'_\mathrm{A} = v_\mathrm{A}/3$), the cart A is stopped shortly after the collision due to resistance forces. The cart B starts moving at slightly higher velocity (theoretical value is $v'_\mathrm{B} = 4v_\mathrm{A}/3$). fg:examples (f) and (g) show the cart velocities in experiments illustrating the conservation of momentum in an explosion. Since the total momentum must stay zero, the abscissae drawn by carts with equal masses are also of equal lengths (figure 2 (f)), and that of carts with mass ratio $m_\mathrm{A} : m_\mathrm{B} = 2$ have lengths roughly in the inverted ratio (figure 2 (g)). The first abscissae just after the explosion cannot be compared as the flashing of the lasers is not synchronized. A slight simplification of abscissa comparison would be achieved by mounting the laser pointers on carts specularly, closer to their common centre, minimizing the unlit space between the glowing traces.

A measurement of the abscissa length can give an estimation of absolute value of velocity. Since the lasers are switched on for a time $\Delta t = D/f \approx 0.1\,\mathrm{s}$, an abscissa with a length of $\Delta x = 5\,\mathrm{cm}$ represents a velocity of $v = \Delta x/\Delta t = 50\,\mathrm{cm/s}$. However, there are methods more appropriate for true velocity measurement.

The main advantage of the presented method is its clear principle. Providing an intuitive visualisation of the velocity just in the place of its incidence, the method is unique especially for introductory classroom demonstrations. Secondary school students, who had seen these experiments, preferred photoluminescent technique to ultrasonic measurement, since they "saw the velocity directly". However, they would take ultrasonic detector if they needed numerical values.

Laser safety. The presented experiment is recommended for teacher's demonstrations rather than for student practice also for safety reasons. The used violet laser pointer with the output power 5 mW and the wavelength 405 nm falls in class 3R [4], containing lasers which might be potentially hazardous for the eyes and which are not recommended for school use in some countries [5]. A directly look into these lasers must be especially avoided. The safety of the experiment is improved with small lenses mounted permanently on the laser outputs. Since the lenses produce strongly divergent beams, the light intensity is decreased to a safe level at distances larger than $\approx 3\,\mathrm{cm}$. Class 2 lasers with output power below 1 mW, recommended for school use in some countries, produce weak traces requiring a classroom blackout. Violet or blue LEDs (light emitting diodes) used instead of lasers create more diffuse traces, even though the LEDs are close to the photoluminescent strip.

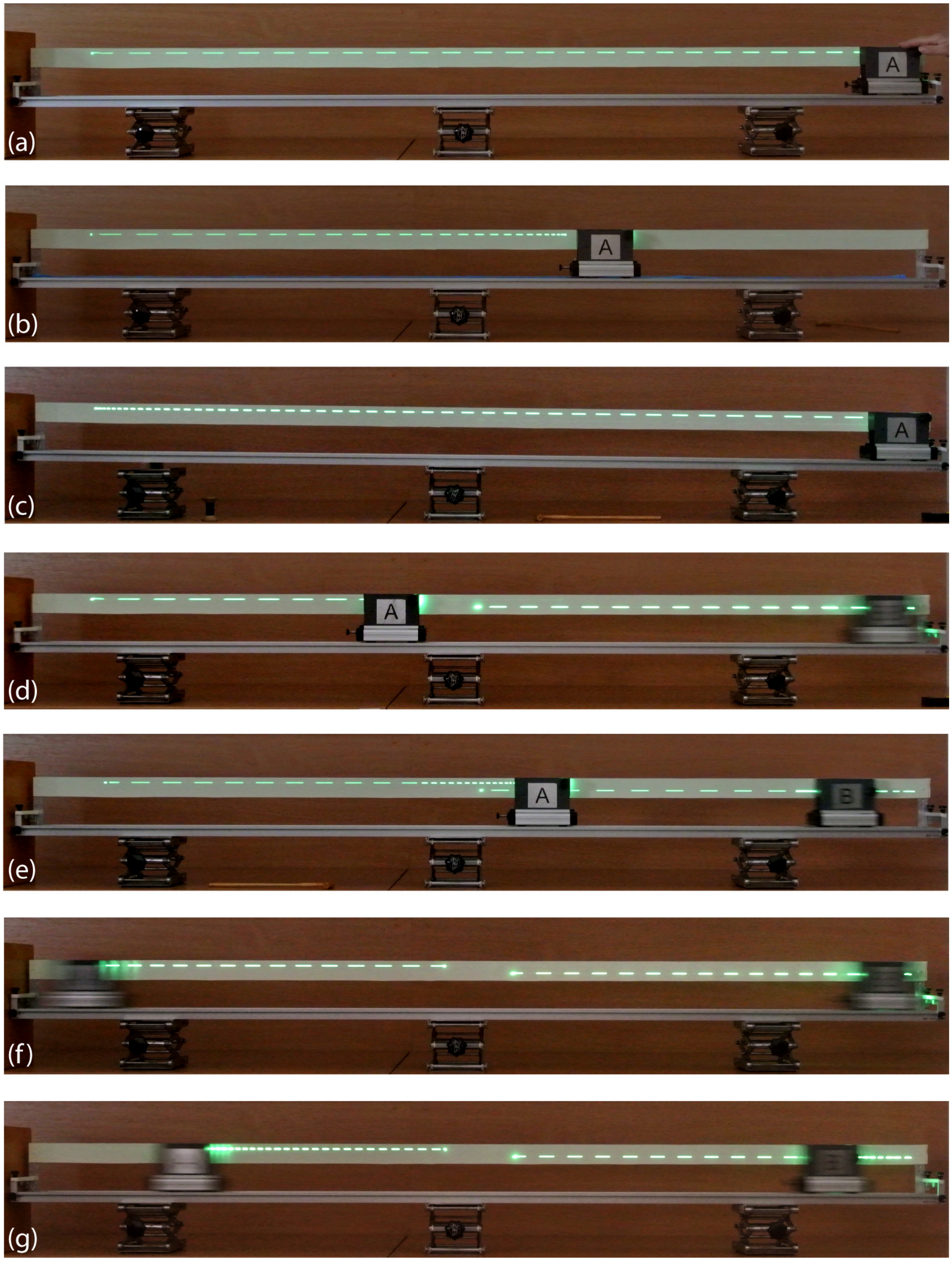

Figure 2: Examples of velocity visualisation on a dynamics track. a) An almost uniform motion with a constant velocity, b) a decelleration on a soft surface, c) an acceleration down an incline, d) – e) a conservation of momentum in elastic collision, cart B at rest before the collision: d) with equal masses, e) with mass ratio $m_\mathrm{A} : m_\mathrm{B} = 2$, f) – g) conservation of momentum in explosion, carts at rest pushed away from each other: f) equal masses, g) mass ratio $m_\mathrm{A} : m_\mathrm{B} = 2$.

References

[1] Navrátil Z and Poláček L 2013 Lissajous figures drawn by a Blackburn pendulum on phosphorescent foil *Phys. Educ.* **48** 282.

[2] Wikipedia. Standard 555 timer integrated circuit. `http://en.wikipedia.org/wiki/555_timer_IC`

[3] Pasco Scientific. Pasco 2.2 m Classic Dynamics System, Instruction Manual and Experiment Guide. `ftp://ftp.pasco.com/Support/Documents/English/ME/ME-9452A/012-05024G.pdf`

[4] IEC Standard 60825-1 Ed. 2 2007 *Safety of laser products – Part 1: Equipment classification and requirements*

[5] CLEAPSS 2013 PS52 Lasers, laser devices and LEDs `http://www.cleapss.org.uk/attachments/article/0/PS52.pdf?Secondary/Science/Guidance%20Leaflets/`