Lecture demonstration on a bench with an air cushion

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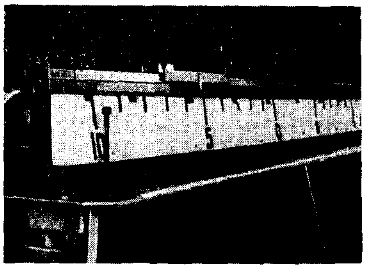
A body can move on an air cushion—a thin layer of compressed air—with practically no friction. This method of decreasing friction has found application in a number of interesting physics-laboratory practical experiments[1-3]. In the physics-demonstrations laboratory of the physics department of the Moscow State University, at the initiative of Professor S. P. Strelkov, motion of bodies on an air cushion is successfully used for lecture demonstrations in a large auditorium. To this end, A. V. Galinskas, K. M. Rogul'skis, and V. D. Pekarskis of the vibration-techniques laboratory of the Kaunas Polytechnic Institute have developed and prepared a special bench with an air cushion.



The bench (see the figure) is made of a duraluminum tube 2.75 m long (1). The surfaces of its rectangular profile (2) are carefully machined and a large number of holes of 0.5 mm diameter are drilled in them. Compressed air fed to the tube by two "saturn" vacuum cleaners escapes through these holes. The excess pressure of the air in the tube reaches 0.1 atm. Riders (3) are placed on the bench, and their internal surfaces are in contact with the surface of the bench and are also carefully finished. The rider is raised above the bench by the compressed air escaping through the holes, and an air cushion is produced under it. In this state, the rider can be either at rest or move along the bench with negligibly small friction. When the vacuum cleaners are turned off, the riders drop on the bench and stop. In a number of demonstrations it is necessary to stop rapidly all the riders simultaneously. A special device is used for this purpose, which swings away the hose of the vacuum cleaner (Fig. 4) from the bench. The riders are made of seasoned duraluminum from 240 to 360 mm in length and weighing 400—600 g. On the air cushion, the rider can be loaded with additional weights and devices, the total weight of which should not exceed the weight of the rider itself. The thickness of the gap between the rider and the bench varies under load between 200 and 50 μ. The minimum thickness of this gap determines the precision tolerances to which the adjacent surfaces of the bench and of the riders are machined. To indicate its position on the bench, the rider is provided with an arrow, and a linear scale with large divisions is marked on the lateral surface of the bench; these divisions are readily seen in the auditorium. To demonstrate elastic collisions of the riders, ribbon-sping buffers (5) are installed on the riders.

The bench with the vacuum cleaners is placed on a special carriage. The carriage is bulky, has a sufficiently rigid construction, and is provided with movable supports, on which it is mounted in the auditorium. Three adjusting screws are used to set the bench horizontal. The adjustment in the horizontal direction is monitored by a level.

To adjust the bench in a longitudinal direction, it is necessary to obtain the state of neutral equilibrium of the riders on the air cushion over the entire length of the bench. This state is maintained at bench inclinations not exceeding ± 0.0001 rad, which corresponds to rotation of $\pm 30^\circ$—40° of adjusting screws spaced two meters apart and with 2 mm pitch. Thus, the order of the friction coefficient does not exceed 1×10^{-4}, and forces of 40—60 mgf (10^{-4} of the weight of the rider) are sufficient to accelerate the riders on the horizontal bench. This sensitivity of the instrument imposes rather stringent requirements on its careful preparation prior to the demonstration at the lecture. However, these difficulties fully pay for themselves in view of the possibility of demonstrating experiments that display relatively small forces and observing motions with small accelerations.

It is possible to use the bench to demonstrate a large number of lecture experiments. An example is uniform linear motion of bodies, which in general is not realized by other demonstration means. A number of simple traditional experiments are demonstrated under considerably more correct and more convenient conditions. Thus, uniformly accelerated motion of a sphere on a Galileo trough usually lasts two or three seconds, and the audience finds it difficult to follow simultaneously the position of the sphere and the time signals. The same experiments on an air cushion can be carried out with a small inclination of the bench and lasts quite long (30—40 sec), thereby greatly facilitating the observation of this demonstration.

Experiments on elastic collisions are performed on the horizontal bench likewise with sufficiently slow motion of the riders. These experiments replace successfully demonstrations on Grimsel carriages, on an instrument for collisions of spheres, etc. It is hardly advisable to list here all the possible variants of the known demonstrations that can be realized with this bench. We present by way of an example the description of only some new demonstrations performed with this instrument.

1. Elastic collision of a small light sphere with a free body of much larger mass. A large loaded rider is placed on the air cushion, and a plumb bob with a light elastic ball is placed alongside the bench near the buffer spring of the rider. The ball is displaced from the equilibrium position and dropped in such a way that it becomes reflected from the buffer sping of the rider as the bob swings. The rider first remains at rest, and only after several collisions of the ball does the motion of the rider become noticeable to the audience and the rider moves away from the plumb bob, moving uniformly on the horizontal bench. This demonstrates the fact that in elastic collisions between a light sphere and a body of much larger mass, the latter acquires a small momentum. To observe this momentum, the method of accumulation of a number of periodically repeated weak pulses by the large-mass body is used. It is desirable to select beforehand experimental conditions under which a single strike of the ball does not set the rider in motion, and demonstrate this circumstance separately.

2. "Magnetic pendulum." Permanent magnets, with like poles facing the center of the bench, are placed on the ends of the bench. A rider equipped with a bar magnet is placed on the air cushion between the magnets; the bar magnet is repelled by the stationary end magnets. From the initial position near one of the magnets, the rider executes vibrational motion along the entire bench with very small damping, moving practically uniformly over the greater part of the bench. This sample demonstration is an example of anharmonic vibrational motion of a body in a square potential well.

3. Drawing of a solid dielectric into a capacitor. The dielectric plate is a rider assembled of thin glass plates that are glued together. At a height 5–10 mm above the bench, parallel to it, is mounted a metallic plate on an insulator. The plate together with the bench form a capacitor. The rider is placed on the air cushion outside the capacitor. After the plates are connected to a high-voltage rectifier, the rider is drawn into the capacitor, passes through it by inertia, stops is drawn again into the capacitor, and begins to oscillate in the inhomogeneous field under the influence of the ponderomotive electrostatic forces.

To prevent the air stream from becoming highly uneven, in the capacitor, a large number of holes of 5 mm diameter were drilled in the metallic plate. The rectifier voltage was 15 kV with an internal resistance 1 GΩ.

4. Demonstration of rolling friction. A rider and a well-center metallic cylinder with accurately finished surface are placed on the bench. After checking the horizontal setting of the bench (the rider is at rest on the air cushion), the bench is gradually inclined by means of the longitudinal-inclination adjusting screw in the direction towards the rider, which begins to move. Attention is called to the fact that the cylinder remains at rest in this case because of the rolling friction moment acting on it, since the compressed air does not disturb the contact between the cylinder and the surface of the bench. The air cusion can be disconnected in this stage. After further increasing the inclination of the bench, the angle reaches a value at which the rolling of the cylinder begins: the moment of the stationary friction forces relative to a cylinder axis already exceeds at this angle the moment of the rolling friction which prevents the rolling at a smaller inclination. In this, principal part of the demonstration the bench is used without an air cushion, as a simple tribometer for rolling friction.

Air-cusion demonstration instruments should help the development of other lecture experiments which are difficult to realize by ordinary means.

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[1]H. V. Neher and R. B. Leighton, Am. J. Phys. 31, 255 (1963).
[2]Ealing Catalogue, 1966–1967, p. 41.
[3]A. Shilton, Phys. Education 6 (1), 25 (1971).

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