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We have built a short Foucault pendulum of 1-m length. The aim of this work was to increase the sensitivity to elliptical trajectories from other longer pendula. The design was a semi-rigid pendulum that rolls over a small ball. The measurements of the movements (azimuth and elliptical trajectory) were done by an optical method. The resulting pendulum works in a medium satisfactory way due to problems of the correct choice of the mass of the bob together with the diameter of the supporting ball. It is also important to keep the rolling surface very clean. © *2013 AIP Publishing LLC*. [http://dx.doi.org/10.1063/1.4825345]

A few years ago we built two Foucault pendulums of 3 and 5 m long suspended with a piano chord which worked very well (Ref. 1). With the longer one we have tried to measure the Allais effect during the total sun eclipse of July 10, 2010 (Refs. 2–4). During the eclipse we only saw deformations of the normal noise that we normally have in the 20 days measurement. So we have tried to increase the sensitivity to measure this effect during the total sun eclipse of November 13, 2012. To do so we increased the oscillation amplitude and decreased the length of the pendulum. We decreased the length to 1 m (increasing the sensitivity by 25 times), kept constant the absolute value of the oscillation amplitude (100 mm), and, as the period became a half, the total increase of sensitivity was finally 50 times. This fact complicated the construction, because an elliptical trajectory of about 0.3 mm of the semi-minor axis generates a precession of 10°/h, which is the total precession of Earth and is the quantity we want to measure quite well. In addition, we could not use the measurement system of the movement that we have used in the earlier 5 m pendulum, because it had problems in the measurement of smaller semiaxis.

The acceleration of the pendulum and the reduction of the elliptical trajectories were done following the same design of the other pendula built (Ref. 1). The pendulum was hung from a three leg support made of steel tubes. A circular table made of wood, supported the acceleration coil, detection coil, and the copper ring, while its horizontal level was regulated over a second wooden table, supported on the steel legs by aluminum angles. All the screws used were made of non-magnetic stainless steel (Figure 1). The main difference with the other pendula built was the hanging support (rolling on ball) and the movement measurement. The latter was built following a laser beam with a position detector (First Sensor model DL400-7PCBA). Figures 2 and 3 show the optical system and the support ball. The pendulum hung from an aluminum basket, which contains at its top a small disc of 9 mm of diameter and 1 mm thick (Figure 4). Both faces were polished up to mirror grade and were made of hard steel (cobalt steel). The lower face rests on the supporting ball (3.5 mm diameter). The upper face is used as a mirror and reflects a laser beam which falls on a square position detector of 20 mm side (Figure 5). The resolution of the position detector is 10 μm, which in terms of the actual position of the bob is 0.2 mm. Significant work was done searching for the best choice of bob weight and supporting ball diameter. Too small diameter and too large weight of the bob damage the disc surface making small holes which hardly affect the rolling of the disc on

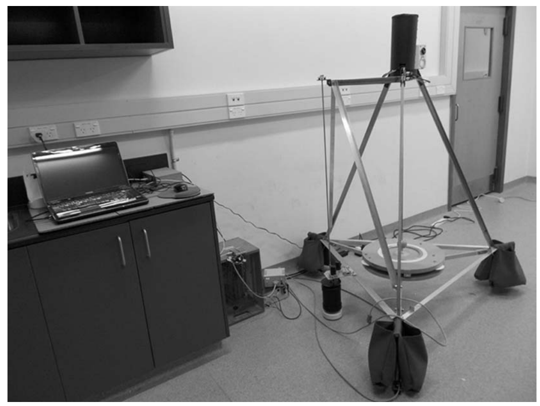

FIG. 1. General view of the pendulum.

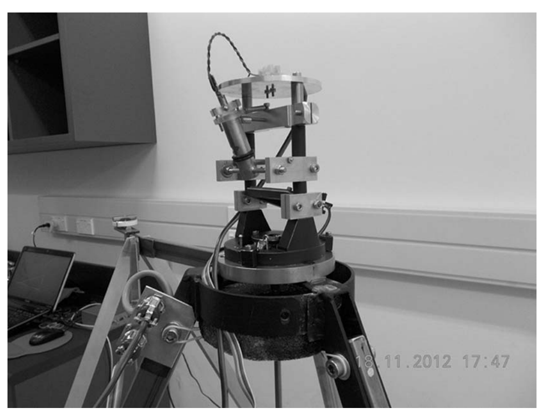

FIG. 2. Optical system of movement measurement, composed of a red semiconductor laser and a position sensor.

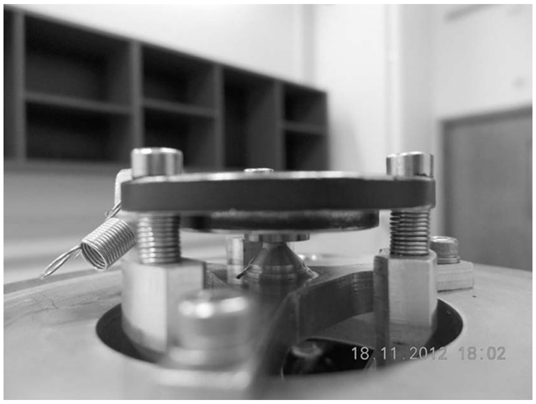

FIG. 3. Side view of the ball support.

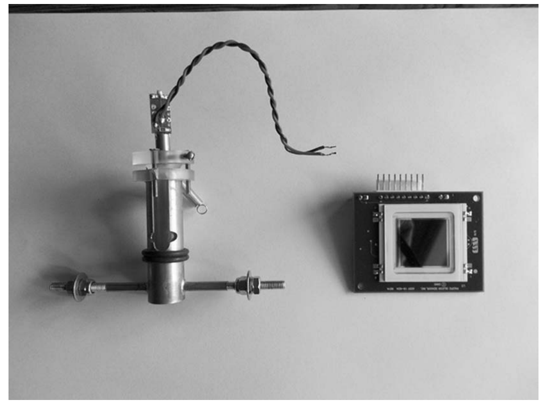

FIG. 5. Laser and optical position sensor.

the ball. After a certain number of essays a ball of 3.5 mm of diameter and a lead bob of 1.1 kg were chosen. Another important issue was the cleanliness of the surface. Any dust that became attached on the surface also changes the normal movement of the pendulum. We have tried to keep the surface as clean as possible adding a small drop of light oil on the ball, which acted as a seal. The solution worked well during a few days. After that time the oil became aggressive to the surface and it began to be damaged. The ball and the disc have to be changed. The basket design of the support allows the pendulum to turn around the vertical axis a small angle ($\sim 60^\circ$).

The measurement program had many problems. One of the most troublesome was the synchronization between the measurement and the pendulum movement. The acceleration electronics was the same used in earlier pendulums. It sends a trigger pulse when the bob is on the center of the movement. This pulse starts the measurement of the bob position during one half cycle. It takes approximately 55 points (half ellipse). With these points we calculate the azimuth plane position (angle, quadrant, and turn number) and the dimensions of the ellipse (major and minor axes). These data let us calculate the total precession speed, the ellipse precession speed, and the Earth precession speed (at our latitude $\sim 9.85^\circ$/h), as the difference between the total precession and the ellipse precession. Finally it plots and saves the main data for each oscillation. Due to the few time available (~ 1 s) sometimes we got problems with the synchronization, which gives once the azimuth and the next oscillation the azimuth plus 180°. This was solved dividing the trigger pulse by the half frequency. Software was also added to auto-repair synchronizations and measurement problems.

Some results are shown in Figure 6. This is a 30 h measurement and shows the azimuth precession and the Earth speed precession. It is seen that the total precession minus the calculated ellipse precession gives the Earth precession as a mean value. The behavior is erratic and we think that it is due to problems in the rolling of the disc on the ball surface.

This is a hard problem that combines hardness of the contact materials and cleanliness of the surface. These problems were improved, but it was not enough to have a clean measurement of the Earth precession speed. No rotation around the vertical axis was detected during normal operation, but it rotates when rolling surface was damaged.

The design of this pendulum was very hard to improve. The main problems were the correct choice, given the materials of the rolling surface and the ball, of the bob weight and ball diameter. Increasing the ball diameter

FIG. 4. Ball and basket support of pendulum.

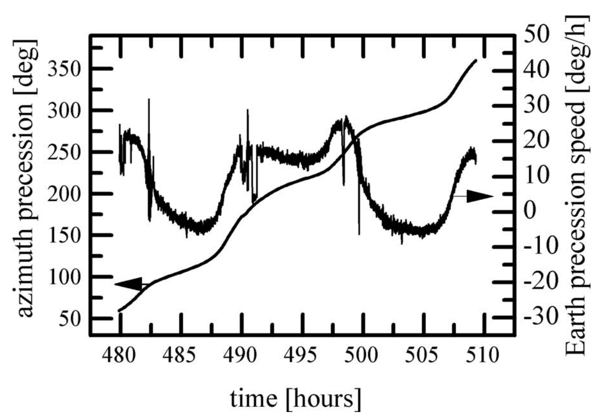

FIG. 6. Typical behavior of pendulum showing the azimuth precession and the Earth precession speed in one day measurement.

increases the anisotropy of the support. Increasing the bob weight spoils the rolling surface. So, it must be a correct relation between them. Also, it was necessary to keep the rolling surface very clean, without any dust or moisture that may perturb the rolling of the pendulum. Ideally, the pendulum should be placed in a "clean room." Despite some kind of erratic behavior, the movement shown is enough to register quick variations on the precession of the pendulum.

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