An experiment to detect Allais effect around total solar eclipse of 9 March 2016

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Abstract. Maurice Allais reported anomalous behavior of pendulums, during solar eclipses in 1954 and 1959. This effect, which is then known as the Allais effect, has been searched for by a number of other researchers. Both positive and negative results had been reported. In this paper we report our pendulum experiment during total eclipse on 9 March 2016, over Indonesia. Apparatus set up and method of measurement are described, and we discuss some points which may contribute to uncertainties of the results.

1. Introduction

In a marathon measurement of several days, before and after the total solar eclipse of 30 June 1954, Maurice Allais had found that during the total solar eclipse, an anomaly in the precession of the plane of oscillation of his paraconical pendulum occured [1]. He observed that, after the eclipse began, the precession of the plane of oscillation reversed its direction and went on to about 13 deg. It then returned to its original direction and precession rate around the eclipse end. Since then many authors had attempted to detect any 'anomaly' that may appears around total solar eclipses; some had succeeded and others had failed. Saxl and Allen [2], for example, observed an anomaly in the period of their torsion pendulum, around the solar eclipse of 7 March 1970. This agrees qualitatively with the observation of Allais [1] in that the greatest change occurs between the onset of the eclipse and its midpoint (see figure 1). However, using an automated Foucault pendulum, on the total solar eclipse of 11 July 2010, Salva [3] found no evidence (within the measurement error) of the Allais effect. Using Saxl-and-Allen type torsion pendulum, Kuusela [4][5] found negative results from measurements during two solar eclipses.

During a solar eclipse in 1995 in India, Mishra and Rao [6] observed a short period temporal variation of $10 - 12$ μgal in their measurement of gravity field with a gravimeter at a region with approximately 80% of eclipse. More positive results about observations with gravimeters during solar eclipses were reported by Chinese team [7] [8]. However, some measurements with gravimeters by others were negative, *e.g.* [9] [10].

Duif [11], and references therein, noted that recent renewed interest in reports about anomalies during solar eclipses might be stimulated by, among other things: (i) realization that our understanding of gravity at galactic scales may be insufficient (giving rise to theories like MOND), (ii) observation of an anomalous acceleration on spacecrafts in the solar system (the Pioneer Anomaly), (iii) anomalous velocity increases of spacecrafts during Earth flybys, and
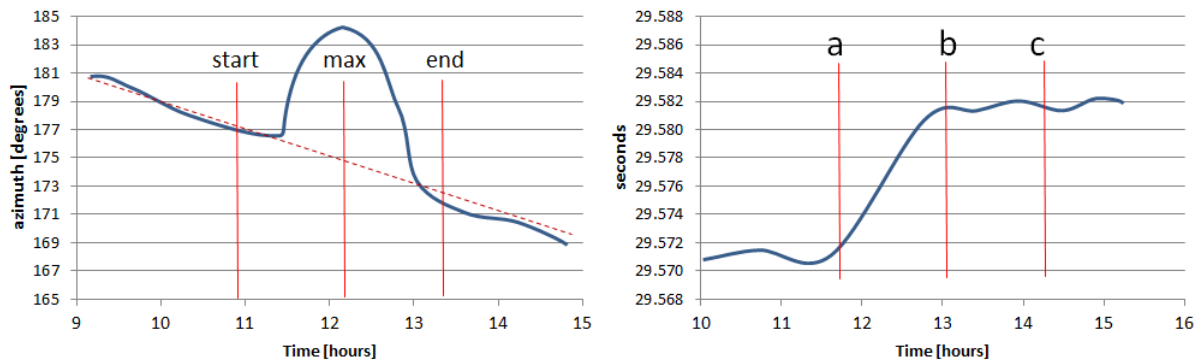
Figure 1. The left panel is adapted from [1], on paraconical pendulum experiment, and the right is adapted from [2], on torsion pendulum experiment. On the left panel, the ordinate is the azimuth of the plane of oscillation of the pendulum, while on the right it is the time used in traversing a constant fixed part of the total vibration path of the oscillating torus on the first swing from rest. Marks of the start, mid point, and end of the eclipse are given in both panels, *i.e.* 'start-max-end' on the left and 'a-b-c' on the right.
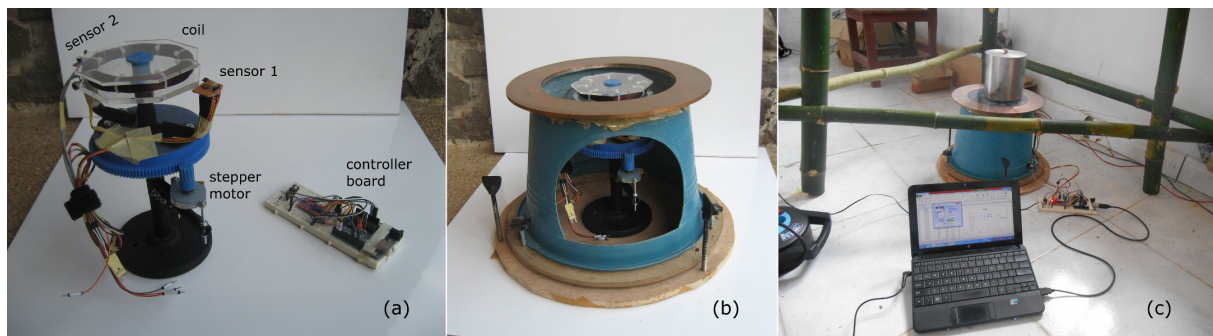
Figure 2. Apparatus setup. (a) assembly of accelerating coil, coil power sensor (sensor 1), plane of oscillation sensor (sensor 2), stepper motor, and the controller board; (b) support for the dumping copper ring (it encloses assembly (a)); (c) the complete setup, including a computer communicating with the controller board and the suspended bob.

even (iv) discussions about whether we understand gravity at laboratory scale. In the following we report our attempt to detect gravity anomaly using a Foucault pendulum during a total solar eclipse on 9 March 2016.

2. Apparatus setup
We build a version of automatic pendulum described in Salva *et al.* [12]. The pendulum is designed to be able to oscillate continuously by adding kinetic energy (through the accelerating coil) once every cycle. The electronics, with the help of an Arduino microcontroller, is designed to be able to record the direction of the plane of oscillation as a function of time. Unlike the original design [12], our system lacks the ability to measure the elliptical motion size needed to calculate the precession rate due to Earth rotation alone.

The pendulum consist of a cylindrical bob weighs around 12 kg which is hung from a mandrel-type support using a steel suspension wire around 4.5 m length (see figure 2 (c)). At the bottom of the bob, at the cylinder axis, we put a small strong permanent magnet which is used to accelerate the bob and to detect the orientation of the plane of oscillation. Below the suspended

bob is an assembly of accelerating coil, dumping copper ring, Hall sensors, and a stepper motor. In non-moving condition, all the parts need to be centrally aligned carefully. The pendulum is independent from the rest of the driving/measuring system so that we can hang it from different support systems.

An oscillation is started by displacing the bob around 1.2 deg, beyond sensor 1, hold it to a complete stop and then release it. When sensor 1 detect the bob approaching from outside the coil will be turned on for a short time, pulling the bob to the center. The bob will then pass, more or less, above sensor 2. Since both sensor 2 and sensor 1 are carried by a rotatable arm, we can position the arm, using the stepper motor, so that sensor 2 is always "exactly" under the path of the bob, hence record the position. Passing sensor 2, the permanent magnet under the bob will interact with free electrons in the copper ring. This eddy current brake is expected to keep the elliptical motion of the pendulum in an acceptable size.

3. Procedure of measurement

For some possible reasons addressed later, elliptical motion in our system always grew to a point where the driving/measuring system failed, in about one hour after we started the oscillation. We found that the one-hour records of the plane of oscillation direction were very similar if we had started the pendulum from the same azimuthal direction. This latter behavior was consistently observed even when the system was operated at two places with 6 degrees latitude difference, and with different type of supports. Accordingly, we decided to adopt the following procedure of measurement.

 (i) Start a measurement from a same azimuthal direction; keep every other condition of the system the same.

 (ii) Record the direction of the oscillation plane until the driving mechanism fails.

(iii) Repeat from step (i).

Two example records are shown on the left panels of figure 3. In those plots, $(0,0)$ corresponds to the start of the oscillation, and the initial azimuthal direction of the oscillation. The pendulum takes some time before reaching a "constant" precession rate in counter clockwise direction. Features on the right end of the curves show the failure of the driving mechanism.

4. Result and discussion

We measured the precession rates of our pendulum at Kalora ($1°12'2''S$, $120°33'44''E$), a village near Poso, in Sulawesi island. Nine records, like that shown in figure 3 (left panels) were obtained, two in 8 March evening and seven in 9 March morning, around the eclipse. For each record we calculated the average slope of the "straight" part of the curve (*i.e.* average precession rate during the measurement). The result is shown in figure 3 (right panel). Although we do not have enough data points, before and after the eclipse, *there is an indication of an increase in average precession rate around the eclipse start.*

Explanations for the anomalous instrument readings during eclipses, based on conventional physics, had been subdivided into 6 kinds by Duif [11], and references therein: (i) seismic disturbances due to increased human activity before and just after an eclipse, (ii) gravitational effects of an increased density air mass spot due to cooling of the upper atmosphere, (iii) tilt due to temperature change of the soil and other atmospheric influences, (iv) tilt due to atmospheric loading, (v) influence of eclipse induced changes of the geomagnetic field, and (vi) instrumental errors. In current experiment our main concern is the instrumental errors.

It is well known that anisotropy of the support system gives rise to elliptical motion. Apparently our support system at Kalora, a tripod made of bamboo, suffers from such anisotropy. We have more rigid support system back in our observatory where we observed less anisotropy during preliminary experiments. The effects of support anisotropy was possibly
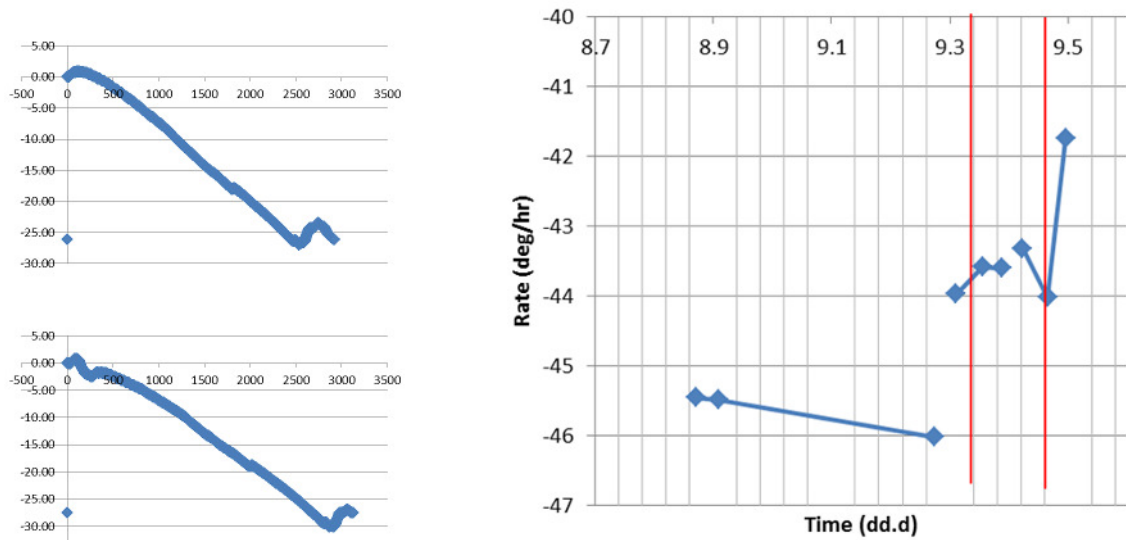
Figure 3. Measurement and result (see text). On the left panels are examples of oscillation plane direction records. The x and y axes are time (in seconds) and azimuthal direction (in degrees), respectively. The right panel shows nine average precession rates around the solar eclipse on 9 March 2016 (UT+8). Two vertical red lines indicate the eclipse start and end.

worsened by slight misalignment of the accelerating coil, and the asymmetry of the coil itself. As our measurement system was unable to compute the size of the elliptical motion, it is impossible to estimate the order of the systematic errors.

Nevertheless, we have have made our first automatic Foucault pendulum and learned a lot about its weaknesses. A plan for improvement is being prepared.

Acknowledgments

References
[1]   Allais M 1957 *C. R. Acad. Sci.* **245** 2001
[2]   Saxl E J and Allen M 1971 *Phys. Rev. D* **3** 823
[3]   Salva H R 2011 *Phys. Rev. D* **83** 067302
[4]   Kuusela T 1991 *Phys. Rev. D* **43** 2041
[5]   Kuusela T 1992 *Gen. Rel. Gravit.* **24** 543
[6]   Mishra D C and Rao M B S 1997 *Curr. Sci.* **72** (11) 783
[7]   Wang Q-S, Yang X-S, Wu C-Z, Guo H-G, Liu H-Cand and Hua C-C 2000 *Phys. Rev. D* **62** 041101
[8]   Yang X-S and Wang Q-S 2002 *Ap&SS* **282** 245
[9]   Ducarme B, Sun H P, d'Oreye N, van Ruymbeke M and Mena Jara J 1999 *JGeod* **73** 53
[10] Mansinha L, Ducarme B, Hinderer J, Meurers B and van Ruymbeke M 2001 *JGSJ* **47** 387
[11] Duif C P 2004 *Preprint* gr-qc/0408023
[12] Salva H R, Benavides R E, Perez J C and Cuscueta D J 2010 *Rev. Sci. Instrum.* **81**, 115102