New Measurements with a Torsion Pendulum during the Solar Eclipse

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During the solar eclipse of 11 July 1991 in Mexico the period of a torsion pendulum was measured in order to reexamine possible anomalies observed in previous experiments of this kind. In our experiment no significant change was found as the relative change in the period associated with the eclipse was less than 2.0×10^{-6} (90% confidence). Results were similar to our previous ones made during the eclipse in 1990 in Finland when the Sun was much lower in the horizon. However, two small but distinct shifts were observed in the horizontal position of the pendulum wire which were well correlated with the beginning and the end of the eclipse.

1. INTRODUCTION

The period of a torsion pendulum during the solar eclipse has been previously measured by Saxl and Allen [1], who found on the solar eclipse of 7 March 1970 a considerable increase in the period. The first reexamination of these effects was made by us with a similar apparatus during the eclipse of 22 July 1990 in Finland [2]. The relative change in the pendulum's period was found to be very small: less than 4.7×10^{-6}. However, our previous work had two drawbacks. Firstly, we used freely oscillating torsion pendulum without any arresting mechanism. This caused the amplitude of the oscillation to decrease exponentially because of friction, and due to some nonlinearities in the pendulum system the measured period

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was not constant. We did not try to find any analytical solution for the period but we used a numerical smoothing method to eliminate the regular amplitude dependence of the period from the measured data. This kind of normalization of the data is not the best way to produce results completely comparable with previous ones. Therefore we have made some modifications to the construction of the pendulum. The pendulum is now arrested automatically after each period measurements, and an accurate temperature control has been added to guarantee the stability of the system. Secondly, the positions of the Sun and the Moon during the eclipse in Finland were quite different than during the eclipse in 1970, when the height of the Sun was 36°. In Finland the first contact occurred when the Sun and the Moon were several degrees below the horizon. From this point of view the eclipse in Mexico was much better: the height of the Sun during the entire eclipse varied between 60 and 80 degrees.

2. EXPERIMENTAL PROCEDURE

The torsion pendulum used in our measurements was the basically same as in our previous work [2]. The pendulum consisted of a brass disk (diameter 247.0 mm, thickness 29.70 mm, mass 12 kg), and a steel wire (length 1.00 m, diameter 1.00 mm). The wire was fastened with help of two bolts to the disk and the support structure made of rectangular steel tubes [height 120 cm, width 35 cm, length, 35 cm; see Fig. 1(a)]. The frame was covered with aluminium sheets to shield the inside against electromagnetic disturbances, and the whole cabinet was coated with thick polyurethane foam to avoid rapid changes in temperature. An additional thermal insulating tube was installed around the pendulum wire. The cabinet was bolted on a heavy slab of concrete.

The period of the pendulum was measured with a light beam which reflected from a mirror attached to the rotated disk close to the wire. The beam was produced by a infrared-light-emitting diode, and in the equilibrium position of the pendulum the beam fell on a phototransistor. The signal from the phototransistor was processed with a precision comparator which triggered a counter unit. The counting was started when the disk passed the equilibrium position clockwise and ended at the next clockwise pass. We measured the total period, because this method was much more accurate than measuring the half-period, as Saxl and Allen did, and it is also not so prone to systematic errors. The counter unit oscillator was crystal controlled with the frequency $1 \times 10^6 \pm 0.05$ Hz.

The pendulum was arrested automatically after each period measurements. Two vertical metal bars were attached on the opposite sides of

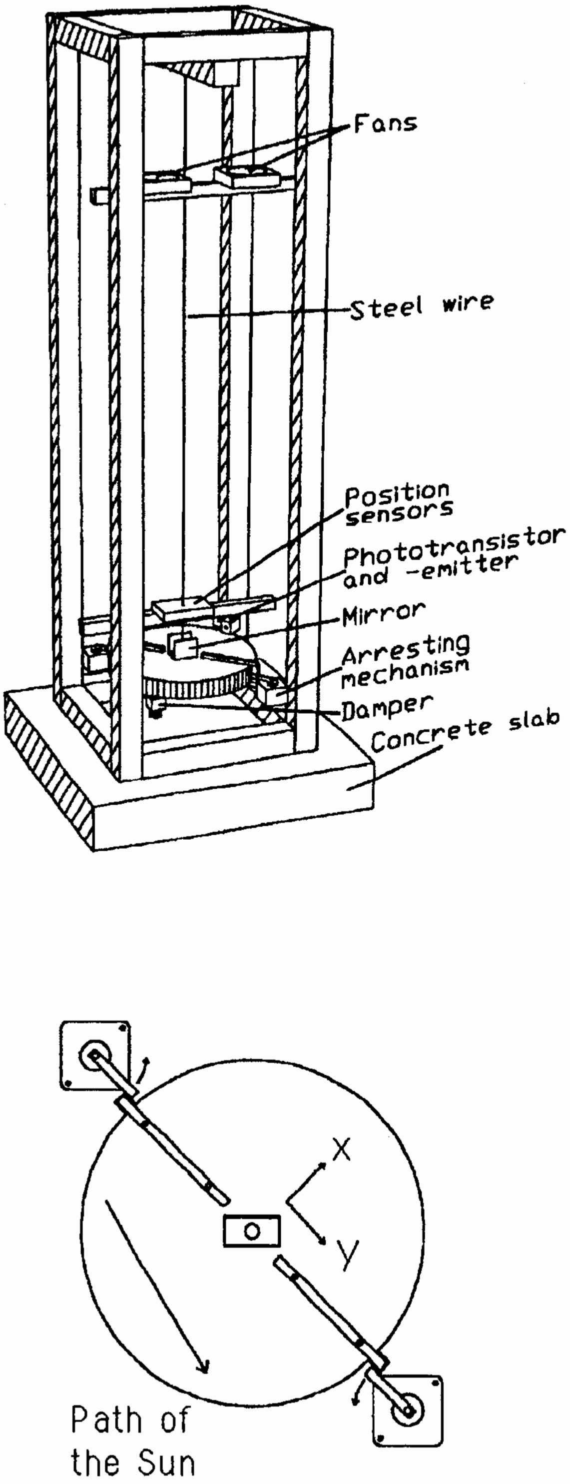

Figure 1. (a) The construction of the torsion pendulum (most support structures of different components is omitted for clarity); (b) The top view of the arresting system.

the pendulum disk with help of four long horizontal bars [see Fig. 1(b)]. When the pendulum was arrested, the vertical bars reclined against two limiter levers whose other end was fastened on the axle of the stepper motor. The pendulum was released by turning off the levers from the front of the disk bars, and was arrested by turning them back to their original position. The surfaces of the levers and the disk bars facing each other were carefully polished. When the disk was arrested the small friction between these surfaces damped out all motions of the disk, and the disk returned to its starting position, which was essential for precise repeated measurements of the period. Experiments with this apparatus have shown that the pendulum returns to the same position within maximum deviation of about 0.005 mm.

After the arresting it was still possible that the disk might oscillate around the y-axle because of a quite small supporting area between the disk bars and the levers. Therefore a damping system was mounted under the disk. In this system a damper tap was smoothly raised against the bottom side of the pendulum disk and then lowered very slowly back to the starting position. This guarantied that the disk was completely at rest before a new measurements of the period, which could be done at every 2 minutes and 27 seconds.

The apparatus was equipped with a optical position sensors which measured the position of the wire in two orthogonal horizontal directions (x and y). The resolution of these sensors were 0.005 mm. Apart from using the sensors to register the movements of the disk during oscillations and thereby to reveal any changes in the support structure or the wire, they were also used for trimming the arresting mechanisms to minimize undesirable oscillation modes after releasing the disk.

The period of the torsion pendulum depends on temperature because the length, thickness, and torsional stiffness of the wire and the dimensions of the disk vary with temperature. We therefore installed a heating cable of helical form inside the cabinet, and two temperature sensors at the bottom and on the top. The top sensor was used to control temperature. As the power dissipation of the stepper motors and the damping system was quite big (6W) compared with the maximum heating power (25W), a thermal gradient was appeared in the cabinet. In order to decrease thermal differences and to improve the thermal control two electrical fans were attached on the top part of the cabinet. The fans were only used at the beginning of the arresting period when the movement of the pendulum was not critical.

The arresting mechanisms, the damping unit and the heating system were controlled by a microcomputer. The temperature was measured about 50 times per second, and the position of the wire 3300 times during each swing of the pendulum. The sensor data and the contents of the counters were saved on a magnetic disk.

3. RESULTS

The experiment was made in Mexico City (19° 20′ N, 99° 11′ W) which lies on the zone of the totality . The first contact happened at 11:54 (local time), when the Sun was 78° above the horizon. The maximum started at 13:21 and ended at 13:27 (the height of the Sun about 80°), and the last contact occurred at 14:47 (the height of the Sun 60°).

The measurement was started 3.5 h before the first contact, and it was stopped 26 h later. Figure 2 shows the period of the torsion pendulum as a function of (local) time. The moment of the first contact is marked with a, the middle of the maximum with b, and the last contact with c. The period seems to be constant within the noise caused by experimental errors.

In order to examine more closely possible effects of the eclipse the time period around the eclipse has been zoomed out in Figure 3. Each dot represents the mean of 10 measurements, and the vertical lines show the mean deviation (90% confidence). The dashed line is the mean (= 23.196002) calculated over the whole data set (630 points). The points lie randomly around the mean line, and there are no obvious anomalities which can correlate with phases of the eclipse. To estimate the experimental errors, the standard deviation was determined for the points in Fig. 3 in the region from the start to the point a and from the point c to the end, determined from their scatter about the mean line. The calculations showed that the change in the pendulum's period was $-1.5 \times 10^{-6} \pm 4.6 \times 10^{-5}$s (90% confidence). By normalizing the times with the period we can conclude that the relative change in the period is less than 2.0×10^{-6}.

The temperature of the cabinet as a function of the time is shown in Fig. 4. The setting value for the temperature was 28°. At the top the temperature change was less than ±0.01°C and on the bottom ±0.05°C. These variations produce a shift on the period smaller than caused by the system measuring the period (the temperature coefficient of the period is about 1 ms/°C).

As the period of the horizontal oscillations of the pendulum is about 2 s, the wire draws a tiny ellipse 10 times during one torsional swing, mostly because of a small deviation of the starting position from the natural rest position of the pendulum. The position of the wire in the horizontal plane was measured over 3000 times during one swing, and the mean x and y

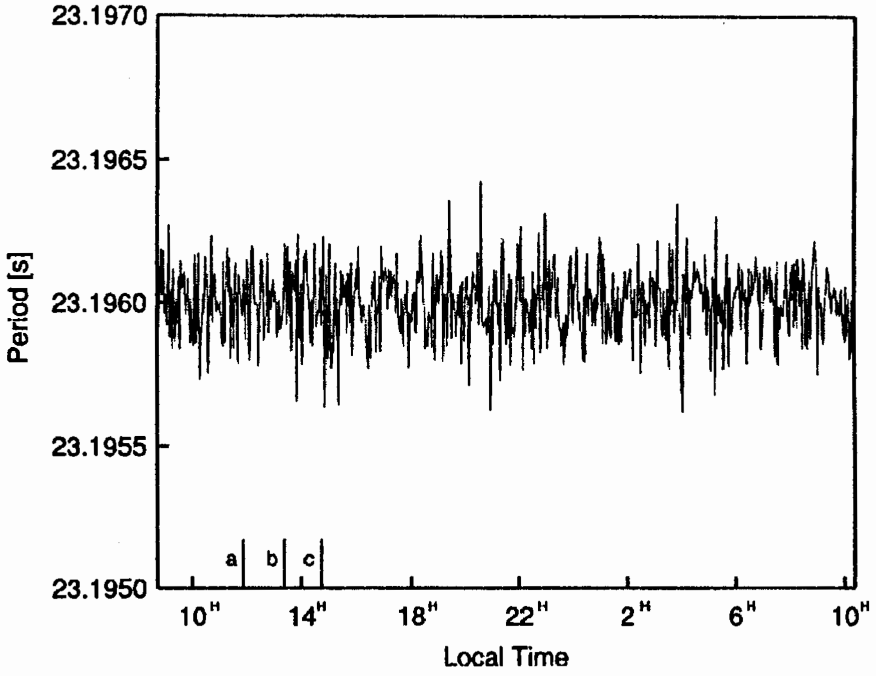

Figure 2. The period of the torsion pendulum as a function of the (local) time. The first contact is marked with a, the maximum with b and the last contact with c.

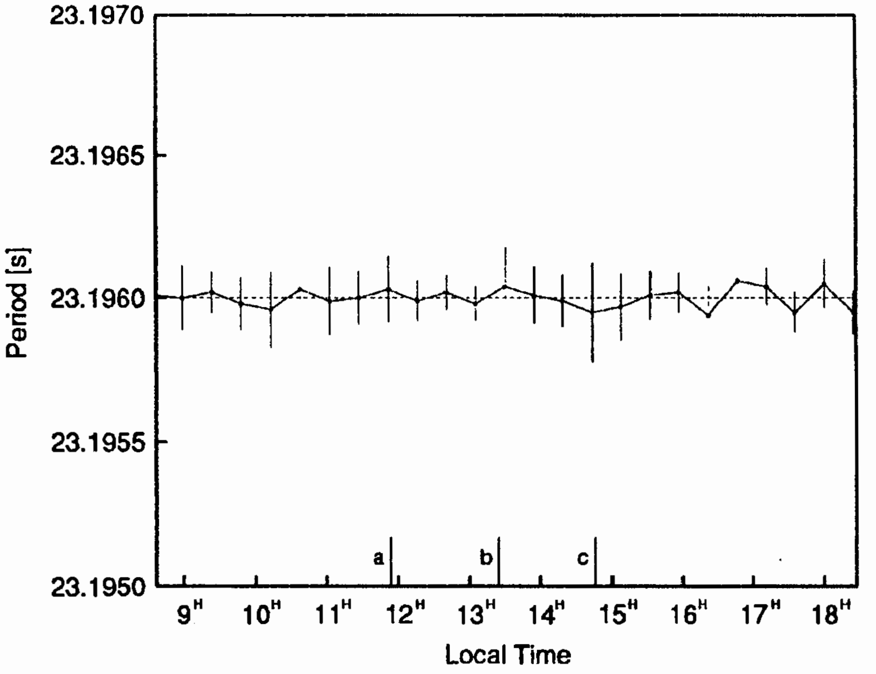

Figure 3. The zoomed period as a function of the (local) time.

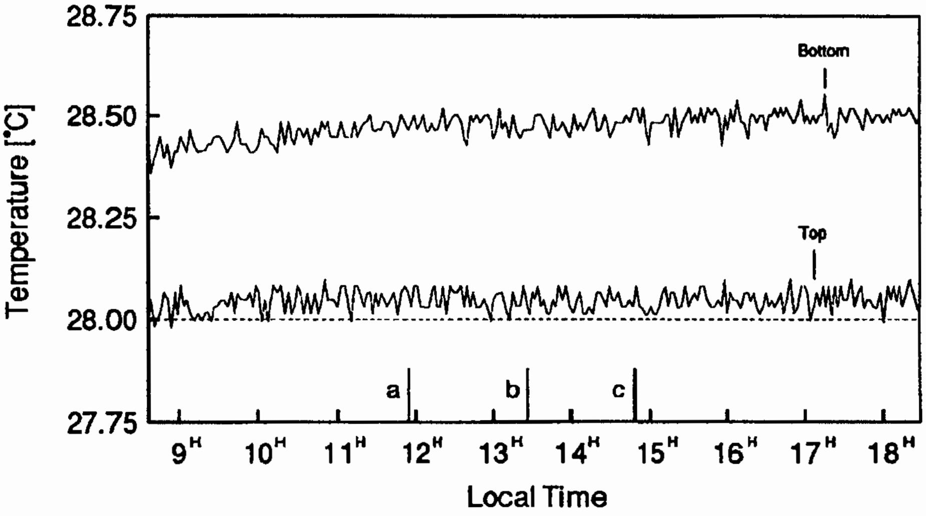

Figure 4. The temperature of the cabinet as a function of the time.

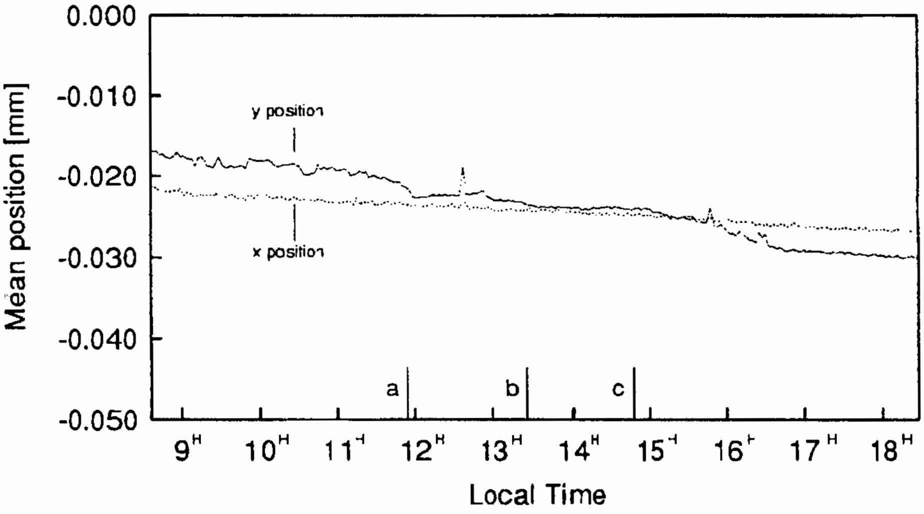

Figure 5. The mean x and y position of the wire in the horizontal plane (x position dashed line, y position solid line).

positions calculated from that data are presented in Fig. 5. There is a slow drift in both positions (probably caused by variations in the temperature of the outside electronics), and the slopes of the curves are almost identical. However, in the y position there are two distinct shifts which seem to appear at the beginning and the end of the eclipse. These shifts are propably due to two possible reasons. Either the position of the support structure has altered, or the amplitude of the horizontal oscillation in the y direction has changed because of dust particles or scratches on the polished surfaces of the arresting mechanisms etc. The last explanation is unlikely as there are no abrupt changes in the x position. These shifts are so small that they have not affected the period data. It is possible that this kind of effect explains the anomalies found by Saxl and Allen, whose measuring method was quite sensitive to any movements on the support structure. Our experiments cannot determine whether these shifts are produced by some eclipse-correlated phenomena, e.g. some sort of tidal waves on the shell of the Earth which has altered the position of the pendulum system.

4. CONCLUSION

The period of a torsion pendulum was measured during the solar eclipse of 11 July 1991 in Mexico City. In this experiment, during which the height of the Sun was between 60 and 80 degrees, no significant increase in the period was observed, as the relative change was less than 2.0×10^{-6} (90% confidence). Results were similar to our previous experiments during the solar eclipse of 22 July 1990 in Finland, when the height of the Sun was only 0.5°. On the basis of these two results we must conclude that earlier experiment made by Saxl and Allen obviously suffered some sort of uncontrollable disturbances.

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