Unexplained Oscillations in Deflection Angle Fluctuations of a Novel Type of Torsion Balance

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For more than four years, fluctuations in the deflection angle $\theta(t)$ of novel type of torsion balance have been monitored at the Main Astronomical Observatory of National Academy of Sciences in Kiev, Ukraine. During this all-year recording, unpredictable spontaneous high-frequency oscillations were observed occasionally. The aim of the present paper was to investigate four of these high-frequency oscillatory events by performing a detailed time-frequency analysis. From the overall available $\theta(t)$ signal, we selected four 24-hour long segments containing a clearly visible oscillations observed on 20 and 21 November 2009 (data segments 1 and 2) and on 24 and 25 December 2012 (data segments 3 and 4). High-resolution time-frequency analysis was performed for each of the four data segments using the generalized S-transform with a hyperbolic window. The oscillation of $\theta(t)$ present in data segment 1 shows clearly an increase in frequency, starting at 0.0002205 Hz (period length $T = 75.59$ min) and ending at 0.0002325 Hz ($T = 71.68$ min). The oscillation of $\theta(t)$ present in data segment 2 has instead a stable frequency of $f = 0.000243$ Hz ($T = 68.59$ min). Both high frequency oscillations of $\theta(t)$ of data segment 3 and 4 show an increase in frequency, starting at 0.006179 Hz ($T = 161.84$ s) and ending at 0.006859 Hz ($T = 145.79$ s) for data segment 3, and starting at 0.005379 Hz ($T = 185.91$ s) and ending at 0.005939 Hz ($T = 168.38$ s) for data segment 4, respectively. In addition, the oscillation present in data segment 3 is periodically amplitude-modulated with a period length of $T = 57 \pm 4.2$ min. Regarding the origin of the observed high frequency oscillation we discuss possible technical or natural factors that could be related to these oscillations.

1 Introduction

At the Main Astronomical Observatory of National Academy of Sciences in Kiev, Ukraine, a high-sensitive torsion balance with a new design (termed "torsind", refering to the device's function as a *tors*ion *ind*icator) has been quasi-continuously measuring fluctuations of its angular deflection since 2009.

The specific design of the device (i.e. replacement of the linear light beam by a light disc of non-magnetic material and the free suspension of the disk with a specific type of monofilament) makes it insensitive to changes in the gravitational potential so that gravitational (tidal) influences from any directions are excluded in the measurements. In addition, since the device is sealed into a container, variations of temperature, pressure, humidity and environmental electric field strength do not influence the reading [1]. Also changes in the excitation of the ionosphere over the place of observation were shown not to influence the measured values of the device [1].

Based on the long-term measurement of the tosind's disc rotations, different types of non-random fluctuations in the time-dependent deflection angle $\theta(t)$ were observed.

The main oscillatory component in the variability is an (amplitude-modulated) diurnal oscillation (i.e. an increase in $d/dt(\theta(t))$ at sunrise, a decrease at sunset and a maximum deflection at noon) [1, 2], having a period length of 1440.24 ± 2.60 min [2], indicating that it is related to solar and not sidereal time (length of sidereal day: 1436 min, solar day: 1440 min). Such a diurnal oscillation was also observed in other experiments where torsion or vertical pendulums were used [3–6].

The fluctuations of $\theta(t)$ measured by the torsind seem also to be related to cosmophysical processes and events since significant changes in $\theta(t)$ were observed during solar and lunar eclipses [1, 7–9], the transit of Venus across the Sun's disk [1], and even specific astronomical configurations [10]. Remarkably, it was observed that the torsind responds to a solar eclipse occurring on the opposite side of the globe [7, 10] or when the measurement is performed underground at a depth of 40 meters [8].

During the all-long recording as a whole, unpredictable spontaneous high-frequency (period length: $T < 24$ h) oscillations were observed occasionally.

The aim of the present paper was to investigate four of these high-frequency oscillatory events by performing a detailed time-frequency analysis.

The motivation to perform this kind of analysis was based on the first author's (FS) previous work on the analysis of unexplained oscillations in electrochemical reactions [11] and diffusion processes [12, 13].

2 Materials and Methods

2.1 Measurement Setup

As described in detail in [1], the torsind device resembles a classical torsion balance but has a very light aluminium disc (diameter: 120 mm, weight: approx. 100 mg) instead of a linear beam. The disc is suspended by a monofilament (diameter: 20 μm) made from natural silk, which has the advantage of not having a reverse torque when twisted. The disc rotation is monitored by a webcam and the image live-stream is processed automatically by custom-made software that determines the angular deflection θ every minute with a standard error of each measurement of ± 0.157° (determined under stable space weather conditions on 13 February 2013) [2].

The device is housed in a quartz glass cylinder (having a high of 240 mm and a wall thickness of 2 mm) with two round glass plates covering the top and bottom. Various efforts were made to isolate the torsind device from environmental changes [1]. To reduce electrostatic influences, the inner wall and the bottom of the glass cylinder are surrounded by a grounded aluminium foil. To ensure that environmental changes in humidity and pressure are not influencing the device, the edges of the quartz-glass housing are sealed with a silicon joint sealant material. The sealing also improves the thermal stabilization.

Measurements were made with the torsind in isolated, shaded room with tightly closed doors and windows at the Main Astronomical Observatory of National Academy of Sciences in Kiev. The place of measurement was selected to ensure that no technical electrical or mechanical processes were happening within a radius of 50 m that could influence the measurement (i.e. no electrical devices, no electromagnetic wireless data-transfer devices, no devices that cause mechanical vibrations).

Concerning the sensitivity of the torsind to detect (extremely) weak forces, the torque (M) of the minimal acceleration value that could be recorded by the device was estimated to be $M \approx 6.5 \times 10^{-12}$ Nm) [1].

2.2 Data

For the analysis presented in this paper, we selected four 24-hour-long signal segments from the overall available signal that contain a clearly visible oscillation. Two of the data segments show a long-lasting fast oscillation with multiple maxima during the 24-hour interval (recording dates: 20 November 2009 [data segment 1], 21 November 2009 [data segment 2]). The other two segments contain a brief, very fast oscillation (recording dates: 24 December 2012 [data segment 3], 25 December 2012 [data segment 4]). Thus, the two distinct oscillatory phenomena investigated in the present study occurred in November 2009 and December 2012. All signals were recorded with respect to Universal Time (UT1) which is the same everywhere on Earth due to its proportionality to the Earth's rotation angle with respect to the International Celestial Reference Frame.

2.3 Time-Frequency Analysis

High-resolution time-frequency analysis was performed for each of the four data segments, applying a specific type of Stockwell (S)-transform, the generalized S-transform (GST) with a hyperbolic window according to the approach developed by Pinnegar and Mansinha [14].

3 Results

3.1 Data Segments 1 and 2

Data segments 1 and 2 contain both a clearly visible oscillation of $\theta(t)$ (see subfigures a1–3 of Fig. 1).

The oscillation of $\theta(t)$ present in data segment 1 clearly shows a frequency increase, starting at 0.0002205 Hz (T = 75.59 min) and ending at 0.0002325 Hz (T = 71.68 min) (see subfigures b1 and c1 of Fig. 1). This is not the case for the oscillation of $\theta(t)$ present in data segment 2 which exhibits a stable frequency of f = 0.000243 Hz (T = 68.59 min) (see subfigures b2 and c2 of Fig. 1).

Subfigures b3 and c3 of Fig. 1 show the time-frequency spectrum of the combined signal (data segment 1 + data segment 2) with the increasing frequency on day one (20 November 2009) and the stable frequency on day two (21 November 2009).

3.2 Data Segments 3 and 4

A very high frequency oscillation is present in data segments 3 and 4.

The high frequency oscillation in data segment 3 started at 746 min and ended at 969 min (total duration: 223 min), whereas the start of the high frequency oscillation of data segment 4 started at 347 min and ended at 549 min (total duration: 202 min) (see subfigures a1 and b1, as well as a2 and b2 of Fig. 2). Thus, both periods of high-frequency activity are of similar duration.

Both high frequency oscillations of $\theta(t)$ of data segment 3 and 4 show an increase in frequency, starting at 0.006179 Hz (T = 161.84 s) and ending at 0.006859 Hz (T = 145.79 s) for data segment 3, and starting at 0.005379 Hz (T = 185.91 s) and ending at 0.005939 Hz (T = 168.38 s) for data segment 4. What distinguishes these two oscillatory events is that the oscillation present in data segment 3 is periodically amplitude-modulated (see subfigure c1 of Fig. 2) whereas such a periodic modulation is not obvious in the oscillation of data segment 4. Three peaks in the variability of the power can be distinguished that correspond to an amplitude-modulation with a period length of $T = 57 \pm 4.2$ min.

Besides the high frequency oscillations, both data segments contain strong shifts of $\theta(t)$. For data segment 3, two significant shifts can be identified within the time frame 318-376 min ($\theta(t)_{start}$ = 232.5°, $\theta(t)_{end}$ = 774.7°, resulting in $\Delta\theta(t)$

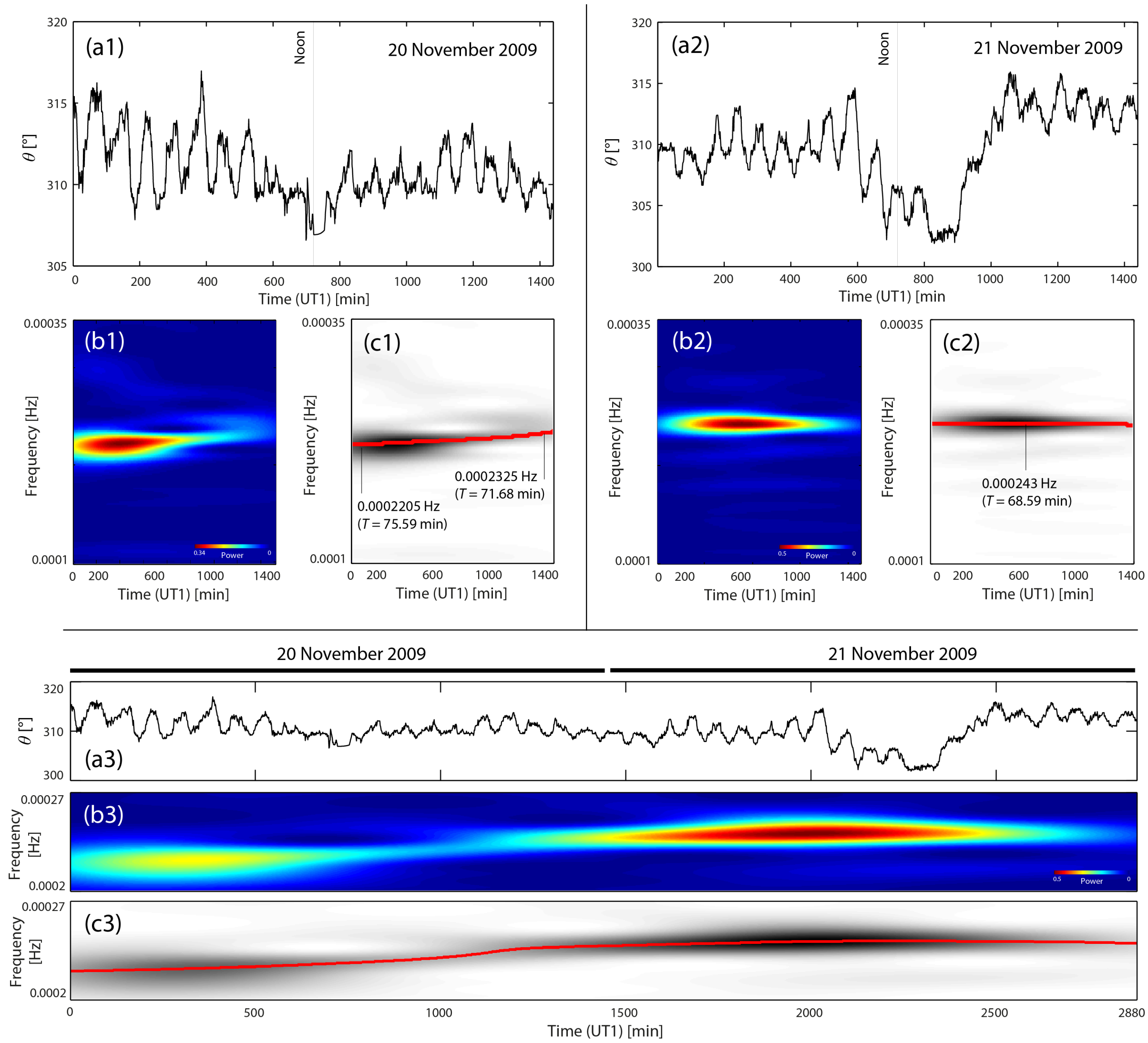

Fig. 1: (a1-a3) Time series of $\theta(t)$ recorded on 20 and 21 November 2009, as well as the stitched time series covering both dates. (b1-b3) Spectrogram showing the time-frequency changes of the oscillation. The power is color-coded. (c1-c3) Spectrogram with red line indicating the maximum power depending on frequency and time.

= 542.2°), and the time frame 1396–1402 min ($\theta(t)_{start}$ = 703.4°, $\theta(t)_{end}$ = 566.9°, resulting in $\Delta\theta(t)$ = 136.5°). In data segment 4, one strong shift is present, occurring in the time frame 1250–1273 min ($\theta(t)_{start}$ = 550.5°, $\theta(t)_{end}$ = 192.3°, $\Delta\theta(t)$ = 358.2°). These kind of shifts (also termed "spikes" [2]) correspond to moments when a strong rotational momentum is acting on the torsind.

4 Discussion and Conclusion

The analysis performed revealed that the fast variations observed in the four days of data segments exhibit oscillations with clearly defined frequencies. The fast oscillations starting at 20 and ending at 21 November 2009 are characterized by an increase in frequency. This characteristic of frequency increase is also observed in the very fast oscillations present in the data from 24 and 25 December 2012.

In the following we will briefly discuss the possibility that these oscillations could be artefacts caused by technical or natural processes, or effects from well-known factors associated with geophysical processes.

Artefacts caused by technical or natural processes. Torsion balance measurements can be generally influenced by changes in the local environmental parameters like temperature, humidity, pressure or electromagnetic fields. The influence of these factors was actively minimized during the measurement with the torsind by applying proper shielding and the effectiveness of the shielding was evaluated experimentally. For this reason, we conclude that it is unlikely that the observed oscillations are simply artifacts due to technical or

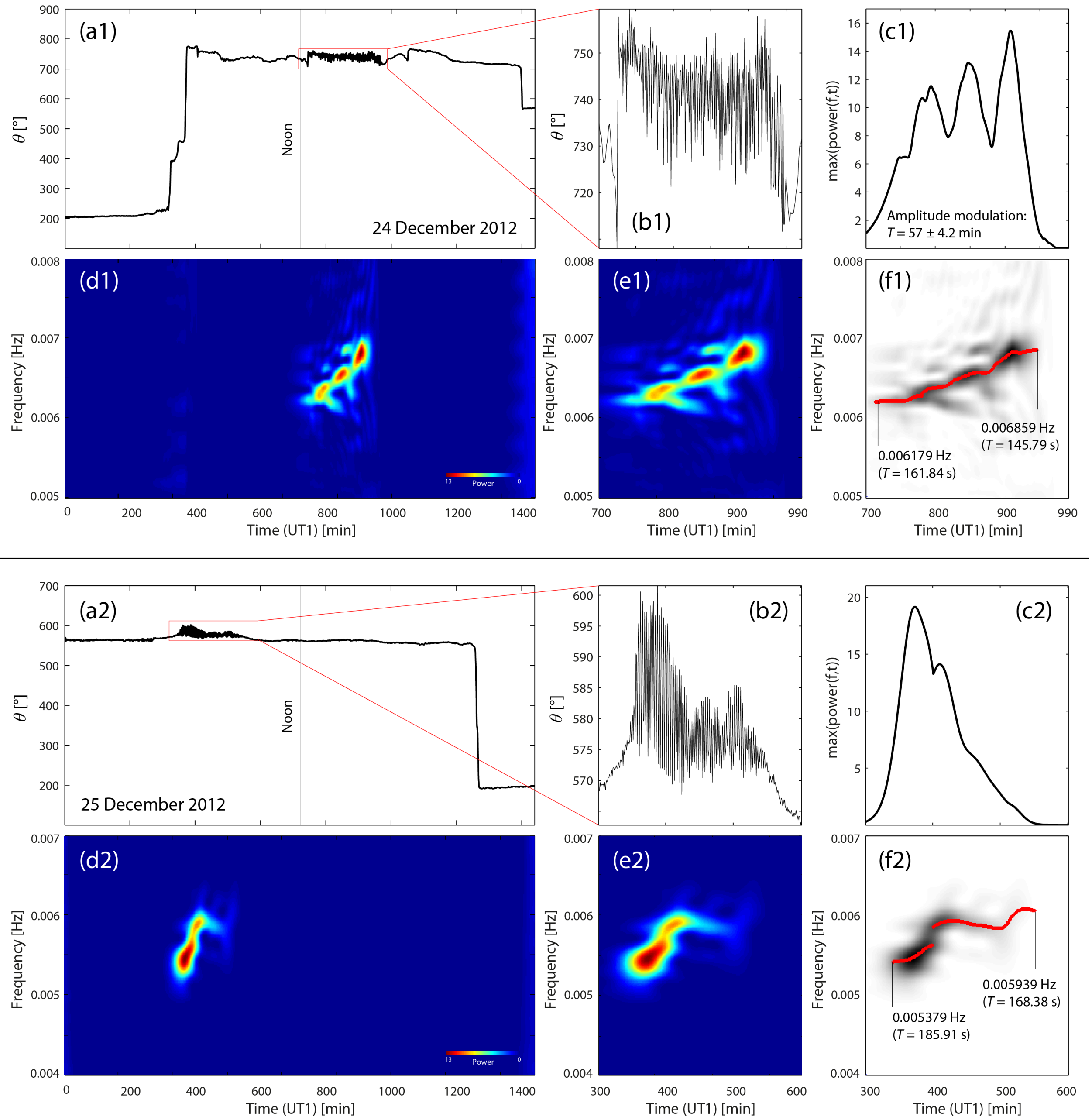

Fig. 2: (a1, a2) Time series of $\theta(t)$ recorded on 24 and 25 December 2012. (b1, b2) Zoom into the intervals with fast oscillations. (c1, c2) Time series of the maximum power depending on the frequency, showing a periodic (c1) and a unimodal (c2) amplitude modulation. (d1, d2) Spectrograms of the entire time series. The power is color-coded. (e1, e2) Spectrograms of the zoomed-in parts of the time series. (f1, f2) Spectrograms with red lines indicating the maximum power depending on frequency and time.

natural processes happening in the local environment of the measurement.

Effects from geophysical processes. What geophysical or astrophysical phenomena exhibit a frequency of approx. 0.002 Hz (as observed in data segments 1 and 2) or approx. 0.006–0.007 Hz (as observed in data segments 3 and 4)? It is known that the geomagnetic field can exhibit periodic fluctuations, termed "geomagnetic pulsations" [15, 16].

Those geomagnetic pulsations in the frequency range of 0.002–0.006 Hz ($T = 166.67 - 500$s), termed "Pc5 pulsations", overlap with the oscillation in $\theta(t)$ found in the present study. Geomagnetic pulsations are the result of solar wind disturbances (caused by increased solar activity) perturbing the magnetosphere and causing disturbances/modulations of the geomagnetic field. We checked whether there were any significant disturbances in the geomagnetic field on the dates of the data segments investigated (20–21 November 2009 and 24–25 December 2012) by analysing the hourly Dcx index (http://dcx.oulu.fi), i.e. the corrected Dst index [17, 18]. Geomagnetic disturbances are seen as negative deflections of the Dcx (and Dst) index, associated with an enhanced westward directed electric current during the geomagnetic storm. During the two periods (20–21 November 2009 and 24–25 December 2012) no geomagnetic storms or significant disturbances occurred. The observed oscillations in $\theta(t)$ can therefore to be regarded as most likely not caused by Pc5 geomagnetic pulsations.

Another principal possibility is low-frequency microseismic oscillations or "long-period seismic noise" [19]. However, it is known that in the range of 0.002–0.02 Hz microseismic activity is the lowest compared to the frequency ranges off approx. < 0.002 Hz and > 0.02 Hz [20, 21]. Also, these kinds of microseismic fluctuations in general do not exhibit the clear frequency stability and do not occur for such a long time span as observed in the $\theta(t)$ oscillations analysed in the present paper. Therefore, we believe microseismicity is unlikely to be responsible for the fast $\theta(t)$ oscillations.

Future experimental work involving measurements with the torsind and data analysis is needed to identify the mechanism causing the non-random fluctuations in $\theta(t)$ measured by the torsind device. Further data analysis is ongoing and will be reported in the near future.

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