Annual & Semi-annual Components in the Geomagnetic Solar & Lunar Daily Variations at Alibag

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The annual and semi-annual components in the first two harmonics of the geomagnetic solar and lunar daily variations (S and L respectively) at Alibag during the period 1932-72 have been calculated. The parameter S shows a dominant annual component with its maximum in summer; the semi-annual component with equinoctial maxima is of much lesser magnitude but is almost equal in both the harmonics of all the three elements, namely, declination and the horizontal as well as vertical intensity. In L, the semi-annual component appears prominent with minima in the equinoctial months.

1 Introduction
Alibag magnetic observatory, established in 1904 and in continuous operation since then, provides a long series of geomagnetic data for a reliable determination of the solar and lunar daily variations of the earth's magnetic field at a low latitude station (geomag. lat. 9°5N) well away from the influence of the equatorial electrojet. Progression of these variations in the horizontal intensity, H, in the calendar months was examined by Rao and Arora, using the data for the period 1932-70. Later, the analysis was extended to a slightly longer period (1932-72) of data and to all the three elements, namely the horizontal and vertical intensities, H and Z, and the declination, D (Ref. 2). A dominant annual variation was noticed in the first three solar daily harmonic amplitudes in D and Z; and in H, it appeared to be a composite of the annual and semi-annual waves. On the other hand, the first three lunar daily harmonic amplitudes in D and Z showed a clear semi-annual variation with minima in the equinoxes. A definitive evaluation of the contributions from the annual and semi-annual components to the solar and lunar daily variations (S and L, respectively) is attempted in this paper.

2 Data and Analysis
Using the hourly values of the three elements, D, H and Z, at Alibag during the period 1932-72, after carefully checking and excluding the days on which even a single hourly value was doubtful or missing as well as the highly disturbed days with the daily magnetic activity index A,p > 100, the Fourier constants of the lunar daily variation, L, were computed by the numerical procedure given by Winch. The first four harmonics of the solar daily variation, S, were also obtained in the process. The analysis was done separately for each of the calendar months, January to December, with the data for all the 41 years and the results were reported elsewhere. Data for over 1,100 days were available in each of the calendar months.

Amplitudes of the solar harmonics were significantly determined in all the months and, though amplitudes of a few of the lunar harmonics, especially of the first, were not well determined, all of them were used in the present analysis. Amplitudes and the corresponding phase angles of the diurnal and the semi-diurnal harmonics, thus derived, were subjected to further harmonic analysis, using the twelve monthly values, to derive the amplitudes and phases of their annual and semi-annual components.

3 Results and Discussion
Amplitudes and phases of the annual and semi-annual components of the first and second harmonic amplitudes of S and L in D, H and Z are given in Table 1, along with the months in which the maxima and minima are reached. The months, January to December, are numbered 0 to 11, starting with the middle of January as 0. The progression of the amplitudes of the first and second harmonics, of only H, and their annual and semi-annual components are presented in Fig. 1 for both S and L.

3.1 Solar Daily Harmonics
The amplitudes of the diurnal and semi-diurnal harmonics are nearly equal in D and Z; they decrease considerably in the winter months (November to February) accompanied by abrupt phase changes. In H, the amplitude of the second harmonic is about half of the first and the phase angles show little fluctuation.
A sharp increase from September to October in the amplitudes of the first and second harmonics of $H$, noted earlier by Yacob and Rao, is clearly seen in Fig. 1.

The annual component (Table 1) is dominant and is of comparable amplitude in both the $S$ harmonics; the highest amplitude is in $D$, and, with an amplitude of 2nT, the annual component in $H$ is the least. The semi-annual component is more or less of the same magnitude in both the harmonics of all the three elements. In $D$, this component shows a phase opposition between the two harmonics, and in the first harmonic of $H$, the maximum of the semi-annual component, occurring in the second half of the year, is around the minimum of the annual component (Fig. 1).

It is to be noted that the ter-annual component (not included in Table 1) is not negligible having amplitudes comparable to those of the semi-annual component. It accounts for as much as 27% of the variation in the first harmonic of $H$ where the annual wave is responsible only for about 50% of the variation. The semi-annual and ter-annual components of the diurnal harmonic in $H$ have their maxima when the minimum in the annual component occurs; this may result in an increased amplitude seen in October-November for the first harmonic of $H$.

The amplitudes and times of maximum of the annual and semi-annual components obtained here for $H$ are

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### Table 1 — Annual & Semi-Annual Components in the Diurnal (1st) & Semi-diurnal (2nd) Harmonics of the Solar and Lunar Daily Variations at Alibag

<table>
<thead>
<tr>
<th>Element &amp; Harmonic</th>
<th>Annual Component</th>
<th>Semi-annual Component</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amplitude nT</td>
<td>Phase deg</td>
</tr>
<tr>
<td>Solar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D_1$</td>
<td>6.1</td>
<td>280</td>
</tr>
<tr>
<td>2</td>
<td>6.6</td>
<td>278</td>
</tr>
<tr>
<td>$H_1$</td>
<td>2.1</td>
<td>336</td>
</tr>
<tr>
<td>2</td>
<td>2.0</td>
<td>301</td>
</tr>
<tr>
<td>$Z_1$</td>
<td>4.8</td>
<td>270</td>
</tr>
<tr>
<td>2</td>
<td>4.3</td>
<td>276</td>
</tr>
<tr>
<td>Lunar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D_1$</td>
<td>0.07</td>
<td>147</td>
</tr>
<tr>
<td>2</td>
<td>0.23</td>
<td>159</td>
</tr>
<tr>
<td>$H_1$</td>
<td>0.41</td>
<td>77</td>
</tr>
<tr>
<td>2</td>
<td>0.52</td>
<td>103</td>
</tr>
<tr>
<td>$Z_1$</td>
<td>0.15</td>
<td>228</td>
</tr>
<tr>
<td>2</td>
<td>0.20</td>
<td>114</td>
</tr>
</tbody>
</table>

Note:
(i) % Variance is the percentage of variability accounted for by the harmonic in total variance.
(ii) Phase angle is reckoned from 15 January.
In comparison with the annual component, the semi-annual component in the solar harmonics of \( D \) is very small (Table 1). Wagner et al.\(^8\) state that an annual as well as a semi-annual variation has been found in \( S_4 \) of \( H \), but, in contrast, only an annual variation, and no pronounced semi-annual variation, appears to exist in \( D \). Speaking in terms of the equivalent current system, they feel that the results seem to indicate that the semi-annual variation of the \( S_4 \) amplitudes is to be explained by the semi-annual variations in the strength of a nearly azimuthal current. Independently, Schäfer\(^9\) finds additional hints to believe that there exists such a zonal component. Earlier, Bhargava et al.\(^10\) have concluded that the component of the semi-annual variation in the evening sector is associated with the modulation of the ring current by disturbance.

The phase angles are nearly steady in both the \( S \) harmonics of \( H \): but for the change of phase in the winter months the variation in \( D \) as well as in \( Z \) is also small. In the variation of the phase angles of \( Z \), the semi-annual component, with equinoctial maxima, is almost in phase in the two harmonics.

### 3.2 Lunar Daily Harmonics

The semi-annual component is generally prominent in both the lunar daily harmonics of all the elements, with consistent equinoctial maxima and solstitial minima; it is the largest in the semi-diurnal harmonic of \( D \) and the least in the diurnal harmonic of \( Z \) (Table 1). The annual component is of considerable amplitude in both the harmonics of \( H \), and has a summer minimum. The phase of the semi-annual component in \( L \) is almost opposite to that in \( S \).

The results of the annual progression of lunar daily variation at Alibag differ considerably from the results for the American sector reported by Campbell\(^11\) wherein it has been shown that the amplitude of the annual component of \( L \) in low latitudes reaches its maximum in the months just after the summer solstice and the maxima of the semi-annual component occur close to the equinoxes. Tarpley and Balsley\(^12\) find that the major seasonal variation in lunar semi-diurnal variation in \( H \), i.e. \( L_2(\hat{H}) \), at Huancayo is annual in period with a single pronounced minimum during the June solstice. Titheridge and Buonasanto\(^13\) have recently reported the results of their investigation on

comparable with the results of an analysis of the diurnal and semi-diurnal harmonics of quiet-day variation in \( H \), viz. \( S_4(\hat{H}) \), at Alibag\(^6\). By a spectral analysis of \( H \) ranges at the Indian stations, Yacob\(^7\) found the power at the annual periodicity to be relatively more important than that of the semi-annual periodicity at stations distant from the dip equator, e.g. Alibag.

References