Analysis on the track unevenness and alidade temperature behavior of TM65m antenna

Li Fu, Quan-bao Ling, Rong-bing Zhao, Jin-qing Wang, Xu-guang Geng, Yong-bin Jiang, Lin-feng Yu, Wei Gou
20th September, 2016

Shanghai Astronomical Observatory, Chinese Academy of Sciences
Outline

• The track unevenness and its effects
  – The foundation settlement and track unevenness
  – The effect of track unevenness on antenna pointing
    • FEM
    • Inclinometer measurement

• The alidade temperature behavior
  – Temperature acquisition system
  – The distribution of temperature field
  – The effect of thermal deformation on antenna pointing

• Further work
  – The temperature behavior of backup structure
  – The effect of wind on the antenna
The foundation settlement and track unevenness

• Leica DNA03 electronic level, invar leveling staff.
• Accuracy: ±0.3mm/km
• Method: closed level route
The foundation settlement and track unevenness

The foundation settlement:
- Jul. 2012~Jul. 2015, 11 times
- The foundation tends to even settlement
- The reasons of the settlements are positive:
  - The variation of groundwater level
  - The settlement of reference point larger than base

The foundation settlement and track unevenness on 4 July, 2015:
- There are relevant between foundation settlements and track heights with variation of the azimuth angle.
- The track unevenness (RMS): 0.47mm
The effect of track unevenness on pointing——FEM

The track unevenness based on the electronic level

Linear interpolation

Extracting the heights of some 6 supporting points of azimuth wheels

Obtaining the $P_4 \cos(az)$ and $P_5 \sin(az)$ by FEA

$$\Delta az = \frac{\Delta Xel}{\cos(el)} = \frac{P_1 + P_2 \cos(el) + P_3 \sin(el)}{\cos(el)} + \frac{P_4 \cos(az) \sin(el) + P_5 \sin(az) \sin(el)}{\cos(el)}$$

$P_4$——inclination of azimuth axis (toward west); $P_5$——inclination of azimuth axis (toward north)\cite{1}

\cite{1} Juan P, Ute L, Rainer M. Pointing with the IRAM 30m Telescope. SPIE, 2000.
Inclinometer measurement system

- **Leica Nivel220 electronic inclinometer:**
  - Range: A:±311 " , B: ±518 " , C: ±619 " ;
  - Resolution: 1 μ rad=0.2 " ; Accuracy: A: ±1.3 " , B: ±3.9 " , C: ±9.7 " ;
  - Zero stability: <0.97 " /°C; Sample speed: minimum 300ms ;
  - RS323 or RS485 interface; two-axis sensor

Fig. The antenna structure of TM65m on the right; a zoom of the inclinometer located on the upper part of the alidade on the left.
The format of data measured by inclinometer

- We compiled data acquisition software to record the inclinometer data and the format is shown as Table 1.
- The elevation tilt (y-tilt), cross-elevation tilt (x-tilt), azimuth and elevation angle, rotation velocity and so on were recorded simultaneously, which will be convenient to analyze data and modify pointing model.

Table 1. The format of data measured by inclinometer.

<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME</th>
<th>X-TILT (mrad)</th>
<th>Y-TILT (mrad)</th>
<th>TEMP (℃)</th>
<th>AZ (°)</th>
<th>Vaz (°/s)</th>
<th>EL (°)</th>
<th>Vel (°/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015-7-29</td>
<td>10:34:01</td>
<td>0.029</td>
<td>-0.015</td>
<td>34.5</td>
<td>153.9993</td>
<td>0</td>
<td>87.9995</td>
<td>0</td>
</tr>
<tr>
<td>2015-7-29</td>
<td>10:34:02</td>
<td>0.03</td>
<td>-0.012</td>
<td>34.5</td>
<td>153.9993</td>
<td>0</td>
<td>87.9995</td>
<td>0</td>
</tr>
<tr>
<td>2015-7-29</td>
<td>10:34:03</td>
<td>0.037</td>
<td>-0.021</td>
<td>34.5</td>
<td>153.9993</td>
<td>0</td>
<td>87.9995</td>
<td>0</td>
</tr>
<tr>
<td>2015-7-29</td>
<td>10:34:04</td>
<td>0.042</td>
<td>-0.012</td>
<td>34.5</td>
<td>153.9993</td>
<td>0</td>
<td>87.9995</td>
<td>0</td>
</tr>
<tr>
<td>2015-7-29</td>
<td>10:34:05</td>
<td>0.038</td>
<td>-0.018</td>
<td>34.5</td>
<td>153.9993</td>
<td>0</td>
<td>87.9995</td>
<td>0</td>
</tr>
<tr>
<td>2015-7-29</td>
<td>10:34:06</td>
<td>0.035</td>
<td>-0.019</td>
<td>34.5</td>
<td>153.9993</td>
<td>0</td>
<td>87.9995</td>
<td>0</td>
</tr>
</tbody>
</table>

......
The track unevenness measured by inclinometer

- Date: June 17, 2015
- The black line: the azimuth rotation in clockwise direction.
- The red line: the azimuth rotation in counterclockwise direction.

- The black line: the azimuth rotation on July 9, 2016.
- The red line: the azimuth rotation on June 17, 2015.
The effect of track unevenness on pointing

The simulation results show a good agreement with the theoretical analysis.

- The effect of track unevenness on the pointing accuracy is within ±4 arcsec.

Rotating azimuth from 0 to 360 degree

Obtaining \( I_x \) and \( I_y \) by inclinometer

\[
I_x(az) = \theta \cos(az - \phi) \\
I_y(az) = \theta \sin(az - \phi)
\]

\( I_x, I_y \) — the readings from inclinometer sensors X and Y; \( \theta \) — the magnitude of the azimuth axis tilt; \( \phi - 90 \) — azimuth angle toward the azimuth axis tilted \(^1\).

\[ P_4 = -\theta \cos(\phi - 180) \]
\[ P_5 = -\theta \sin(\phi - 180) \]
The track unevenness—linear and nonlinear parts
The effect of track unevenness on pointing —— nonlinear part

- The left figure:
  - Black line: x tilt measured by the inclinometer
  - Red line: sinusoidal fit from the inclinometer measurement
- The right figure: residuals after subtracting the sinusoidal fit from the inclinometer measurement.
- Further work: creating an azimuth-track-level look-up table and adding it to pointing model to modify the effect of this nonlinear part on pointing.
Temperature acquisition system

- **System components**: thermometers, master node controllers, electricity supplies, computer and cables.
- **Thermometer**: DS18B20 digital thermometer, ±0.5 °C (temperature range of -10 °C to +85 °C).
- **Location and number**: totally 56 thermometers that were installed on the four sides named a, b, c and d of 14 nodes respectively.

Fig. The display interface measured temperature and installation positions of thermometers on the left; the schematic diagram of thermometer number on the right.
The distributions of temperature field of alidade

- Parked position: azimuth angle=155°, elevation angle=89°.
- Date: July 30, 2015 and February 9, 2016.
- Illustrations: green line is cross-elevation tilt with time and the others are variations of average node temperature (the average temperature of 4 sides of every node).

Fig. The variations of average temperature of nodes and cross-elevation tilt with time.
The distributions of temperature field of alidade

2015/7/30, 77°

2016/2/9

17:31 18:47

44°

6:44 5:13

W

E

N

S

Table 2. The comparison of results.

<table>
<thead>
<tr>
<th></th>
<th>Feb. 9</th>
<th>Jul. 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>The solar elevation angle</td>
<td>44°</td>
<td>77°</td>
</tr>
<tr>
<td>The length of sunshine</td>
<td>10.8 hrs</td>
<td>13.6 hrs</td>
</tr>
<tr>
<td>The maximum diurnal temperature difference</td>
<td>27.0 °C</td>
<td>14.6 °C</td>
</tr>
</tbody>
</table>

• Results:
  - In summer, the day-length is longer and the sunrise is earlier so the structural temperature rises smoothly.
  - However, shorter sunshine time and later sunrise contribute to the temperature variation per unit time is larger in winter.
The cross elevation tilt—FEM+Inclinometer

- The left figure: variations of node temperature and inclinometer with time.
- The right figure: the comparison between the inclinometer measurement and FEM.
- The temperature induced cross elevation pointing error: 1.7 arcsec /°C.
The effect of thermal deformation of alidade on pointing

- April 30, 2016: fine, clear and calm day.
- Source: polestar, 2344+8226.
- Results:
  - good agreement pointing check and inclinometer measurement
  - Around 20 arcsec pointing error from 8:00 to 10:00 am

Fig. The polestar motion locus.

Fig. The EL offset with time.
The relationship between inclinometer reading and azimuth and elevation

- Independence of the inclinometer reading on elevation
- Dependence of the inclinometer reading on azimuth
Further work

1. The temperature behavior of backup structure (36 sensors) and sub-reflector legs (12 sensors)

- **Methods:** FEM + Temperature measurement
- **Aims**\(^2\):
  - Temperature induced the deformation of the primary reflector surface
  - Temperature induced the variation of the focal length

---

Further work

Wind vibration test system

- **Hardware:**
  - 130-MC12A/AC220 Recorder, Multi-Channel, 12, Single DAS Enclosure, 220V

- **Software:**
  - Command Line GUI, 130-SM
  - 130 DAS's, Command Line
  - REF TEK Interface

- **Accelerometer:**
  - SLJ100-FBA: single axis, tri-axis
  - Test range: ±2g
  - Dynamic range: >135dB
  - Sensitivity: 2.5v/g
  - Noise: <10^{-6.75}g
  - Bandwidth: 0~80Hz
  - Zero drift: <100 µg/°C
Further work

2. The effect of wind on the antenna based on the accelerometer.

- **Methods**: FEM + Accelerometer + PSD + Pointing test
- **Aims**[^3~5]:
  - Wind induced the pointing error at elevation and cross-elevation directions.
  - Relative position relationship between the sub-reflector and the feed.

Thank you!