Portable Calibration Standard Capabilities

Ivan Prochazka, Karel Hamal,

Czech Technical University in Prague
Brehova 7, 115 19 Prague, Czech Republic, fax +420 221912252, prochazk@mbox.cesnet.cz

The principal idea behind the Portable Calibration Standard (PCS) is the high degree of redundancy in a measuring hardware, data analysis software and operational procedures. Using an independent measuring instrument or procedure, the possible error source may be identified. Additional error sources may be identified with the help of PCS using additional procedures not used in a routine SLR operation. The survey accuracy may be verified by ranging to several ground targets and evaluating the corresponding system internal delay. The error induced by the correlated radio frequency noise may be estimated by ranging to ground targets at different distances. The PCS is capable to identify most of the systematic error sources introduced by the ranging machine.

The first generation Portable Calibration Standard [1] has been based on the Stanford Research Time Interval counter SR620. Two PCS units have been operated in Japan and China as a part of the Western Pacific Laser Tracking Project. The second generation PCS is based on the Pico Event Timer (P-PET) device [2].

The PCS missions to totally 9 satellite laser ranging stations have been completed within the last five years. The problems in operation procedures, local time base, calibration targets configurations, ground survey, meteo sensors and data processing have been identified [3]. The calibration mission to the SLR Herstmonceux, UK provided a detailed analysis of the time interval counters used for ranging, namely the time interval linearity and its range dependence, the time and temperature stability.

The Portable Calibration Standard based on the Pico Event Timer is a powerful diagnostics tool capable to reveal most of the systematic errors of the satellite laser ranging machine. The excellent performance of the Pico Event Timer in terms of time resolution, linearity and stability permits to use it as a reliable calibrator of timing devices used on the satellite laser ranging sites. The compactness and operational simplicity of the entire Portable Calibration Standard enable its fast re-location and installation on various satellite laser ranging sites.

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References:
Portable Calibration Standard for SLR Capabilities

Goals

- Creating the tool for SLR systems inter-comparison and standardization
- Satellite Laser Ranging machine diagnostics, identification of error sources due to:
  - epoch and time interval timing
  - epoch and frequency reference
  - data acquisition, filtering and processing
  - calibration scheme and ground survey
  - operational procedures
  - radio frequency interference
  - other sources (?)

Philosophy

- high degree of redundancy
- based on top quality and certified hardware
- independent on SLR under test
  - signal processing and cabling
  - grounding, power line, RF shielding
  - timing (time interval, epoch)
  - calibration targets and ground survey
  - data acquisition and data processing
  - staff
- operated in parallel to existing SLR
- easy to re-locate (personal luggage)
Portable Calibration Standard for SLR Capabilities

Block Scheme

Figure 1: Portable Calibration Standard block scheme

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PCS Capabilities - Comparison

<table>
<thead>
<tr>
<th>Systematic error source</th>
<th>collocation</th>
<th>Portable Calibration Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>frequency and epoch</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>mount eccentricity</td>
<td>yes</td>
<td>partially</td>
</tr>
<tr>
<td>correlated RF noise</td>
<td>yes</td>
<td>partially</td>
</tr>
<tr>
<td>instrumental errors</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>stability</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>echo signal strength</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>data processing</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>operator errors</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>shot by shot comparison</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>atmospheric data</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>experiment complexity and costs</td>
<td>&gt; 10</td>
<td>1</td>
</tr>
<tr>
<td>time frame</td>
<td>&gt; 10</td>
<td>1</td>
</tr>
</tbody>
</table>

PCS (1G) in Changchun, Time Bias

Time bias SLR-PCS [usec]

Day of August '97

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P-PET in Graz, Calibration Stability

![Graph showing calibration drift over time with SLR Graz and Portable Calibration Standard data.]

Kirchner, Kold, Hamal, Prochazka, Graz 97

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P-PET Results Summary, Shanghai 2001

<table>
<thead>
<tr>
<th>Satellite</th>
<th>P-PET rms (mm)</th>
<th>SLR rms (mm)</th>
<th>Time bias (us)</th>
<th>Rng. bias (ns)</th>
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<tbody>
<tr>
<td>Starlette</td>
<td>7.5</td>
<td>12.7</td>
<td>0.1</td>
<td>0.02</td>
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<tr>
<td>Beacon-C</td>
<td>9.3</td>
<td>13.8</td>
<td>0.1</td>
<td>0.00</td>
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<tr>
<td>Ajisai</td>
<td>10.9</td>
<td>15.9</td>
<td>0.1</td>
<td>0.00</td>
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<tr>
<td>Lageos 2</td>
<td>10.5</td>
<td>17.3</td>
<td>0.1</td>
<td>-0.01</td>
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<tr>
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<td>15.1</td>
<td>0.1</td>
<td>0.03</td>
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<td>14.2</td>
<td>0.1</td>
<td>0.01</td>
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<td>19.7</td>
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<td>0.1</td>
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<td>0.1</td>
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<td>0.01</td>
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<td>Westpac</td>
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<td>0.1</td>
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<tr>
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<td>16.1</td>
<td>0.1</td>
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<tr>
<td>Stella</td>
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<td>11.5</td>
<td>0.1</td>
<td>0.00</td>
</tr>
<tr>
<td>ERS-2</td>
<td>4.0</td>
<td>10.5</td>
<td>0.1</td>
<td>0.01</td>
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<tr>
<td>mean</td>
<td></td>
<td></td>
<td>0.1</td>
<td>0.01</td>
</tr>
</tbody>
</table>

No significant dependence identified
P-PET at Shanghai 2001, Conclusion

- SLR rms reduction down to 4.0 and 8 mm from original 10 and 14 mm for ERS-2 and Lageos, respectively, 2.5 sigma rejection

- time and range biases below the resolution limit 0.1 usec and 2 mm respectively

- three ground targets calibration consistency within +/- 2mm (final set-up)

- routine SLR calibration procedure problem identified and solved

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SR620 / P-PET Counter Linearity
Potsdam, 29.8.2001, Starlette satellite passes

Peak to peak 130 psec within 6-12 msec
not reproducible

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Portable Calibration Standard for SLR Capabilities
SR620 / P-PET Counter Linearity
Potsdam, 2001, LAGEOS pass

50 ps / div  Counter s/n 1014 (in routine use)
non reproducible oscillations
offset - 51 ps
the same measurement, 3 hours later
offset - 45 ps


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Portable Calibration Standard for SLR Capabilities
SR620 / P-PET Counter Linearity
Potsdam, 2001, Short times

10 ps / div  Counter s/n 1014 (in routine use)
the same, later on
40 ps


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P-PET at Potsdam SLR
SR620 counters test - Summary

- counter reading jumps of 40 psec
  random, not reproducible

- oscillations 50 psec amplitude, period ~ 60 sec
  not correlated

- offset 20-50 psec between the nanoseconds
  (calibration) and milliseconds (SLR) ranges

=> SYSTEMATIC ERRORS 45-80 psec

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Portable Calibration Standard for SLR Capabilities

Conclusion

• Portable Calibration Standard based on a Pico Event Timer
  is a powerful tool to identify systematic error sources in the
  SLR “ranging machine”

• the entire system is compact, easy to transport fast to install
  and user friendly to operate,
  the calibration mission can be accomplished within one week
  time slot,

• P-PET mission to SLR sites did trigger several projects
    timing systems upgrade
  - European millimeter SLR joint activity (2002),
  - Herstmonceux Workshop (2002)

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