Reflective Shape Measurements

Solar Mirror Shape

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Reflector Shape is a Key Property of Concentrating Solar Systems
How does the focal area look like?
Collector Geometry Qualification

- Geometry
- Module reference
  - mirror alignment
  - receiver alignment
- Collector reference
  - alignment between modules and drive
  - in all collector angles
- Also in series production quality control
Mirror and Concentrator Geometry

- Mirror shape (component level, assembly level)
- Concentrator structure
- Collector assembly
- Performance is related to geometry accuracy
- Performance figure is the intercept factor

- Intercept factor is only applicable to assembly under operation conditions
- Intercept factor is not applicable to individual components

- Needed: easy-to-handle figure of merit
  (Answer will be: Slope deviation, Focus deviation)
Mirror Shape Measurement Methods

• Laser reflection count
• High-Density Close-Range Photogrammetry
• Deflectometry (Fringe Reflection)
Photogrammetry on Mirrors

- Measure Mirror Shape
- Measure Slope and Slope Deviations
- Calculate Optical Efficiency
- Measure Deformation due to dead-load etc.
Photogrammetry on Collectors
Concentrator-Quality 3-dimensional, EuroTrough
EuroTrough Skal-ET Collector Qualification
Photogrammetry, Efficiency Measurement

Flux distribution around absorber tube
Quality Control during Collector Assembly
Geometric Precision Study over large Collector Areas
“Distant Observer” Techniques
Reflection Image Analysis

• Receiver is imaged, thus couples receiver position/shape to concentrator optics
• Potential for large mirror areas (module level) to be characterized quickly; does not provide point by point surface measurement (i.e. suited to fast module/mirror panel/receiver alignment)
• Examples:
  • Theoretical Overlay Photographic Alignment System (TOP)
  • TARMES Reflector Analysis
  • QDec Pattern Techniques
TARMES Absorber Tube Reflection
Laser Techniques (NREL)

- Laser beam reflected by the concentrator mirror
- Scanning laser
- Analysis of the position of the reflected laser on a target

- VSHOT (NREL)
QDec Reflector Analysis
“Deflectometry” or “Fringe reflection”

- Based on image recognition of a target in the reflector
- measure coordinates of many points in one step
  - lines/grids instead of points, for higher speed

detector: digital camera
- high resolution:
- detector data = foto
Deflectometry Application Examples

- Troughs, Heliostats, Dishes
- Mirror Facets
- flexible measurement systems
- high spatial resolution and precision
- fast
- industrial application
Flexible Application for all Types of Concentrator

Dishes

Heliosstats

Panels (Fresnel, Dishes, Parabolic Trough)
Deflectometry Measurement setup (QDec)
Trough Mirror Panels
Slope deviation graph through mirror panels, in mrad
Focus Deviation Map
Deviation of reflected ray in mm
Focus Deviation Distribution Function

Standard deviation = Quality!
## Measurement result (trough mirror panel)

<table>
<thead>
<tr>
<th>slope</th>
<th>height</th>
<th>focus deviation</th>
<th>intercept</th>
</tr>
</thead>
</table>

![Graph 1](image1.png)

![Graph 2](image2.png)

![Graph 3](image3.png)

![Graph 4](image4.png)
Definition of Focus Deviation and Slope Deviation based on measurement data

\[ FD_x = \sqrt{\sum_{i=1}^{n} \left( F D_{x_i}^2 \cdot \frac{a_i}{A_{ges}} \right)} \]

\[ FD_y = \sqrt{\sum_{i=1}^{n} \left( F D_{y_i}^2 \cdot \frac{a_i}{A_{ges}} \right)} \]

\[ SD_x = \frac{FD_x}{2f_m} \]

\[ f_m = \sum_{i=1}^{n} \left( f_i \cdot \frac{a_i}{A_{ges}} \right) \]
Optical Beam Spread
statistical approach to large number of influence parameters

- sun, mirror shape and specularity, structure, receiver position, tracking/torsion, other mech. loads
- $\sigma^2_{\text{total}} = \sigma^2_{\text{sun}} + \sigma^2_{\text{optical}}$
- $\sigma^2_{\text{total}} = \sigma^2_{\text{sun}} + 4 \sum \sigma^2_{\text{contour}} + \sum \sigma^2_{\text{spec}} + \sum \sigma^2_{\text{structure}} + \sum \sigma^2_{\text{recpos}} + \sum \sigma^2_{\text{track}}$

$$\sigma^2_{\text{optical}} = 4\sigma^2_{x,\text{contour}} + \sigma^2_{x,\text{spec}} + \lambda(\phi)(4\sigma^2_{y,\text{contour}} + \sigma^2_{y,\text{spec}}) + \sigma^2_{\text{displ}} + \sigma^2_{\text{track}}$$

$$\lambda(\phi) = (1 - \frac{\phi}{2\tan\frac{\phi}{2}})\tan^2 \theta$$

$$\sigma^2_{\text{sun,line}} = \frac{\sigma_{\text{sun,shape}}}{\sqrt{2} \cos \theta}$$
Quality criterion: total beam spread
typical example

![Diagram showing the quality criterion: total beam spread.](image)

<table>
<thead>
<tr>
<th>Category</th>
<th>$\sigma$ in mrad</th>
<th>$\sigma^2$ in mrad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror Shape*</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>Beam Spread</td>
<td>0.2</td>
<td>0.04</td>
</tr>
<tr>
<td>Mirror Support*</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Absorber Position</td>
<td>1.5</td>
<td>2.25</td>
</tr>
<tr>
<td>Collector Torsion (Loads)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Module Alignment</td>
<td>1.5</td>
<td>2.25</td>
</tr>
<tr>
<td>Tracking Accuracy</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sun</td>
<td>3.5</td>
<td>12.25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6.24</strong></td>
<td><strong>38.79</strong></td>
</tr>
</tbody>
</table>

Intercept Factor: **98.7%**
Flux density distribution is characteristic for the reflector shape
Parascan – Flux Density Measurement on Absorber Tube
Intercept values EuroTrough Collector
Intercept Measurement with Camera Target

Intercept measured with Camera Target Method
EuroTrough PSA, August 2004

Average: 95.7%

ET on PSA (with new Schott absorber tubes)
Application Examples for Shape Measurements
Production Quality Assurance of Concentrator Mirrors: Deflectometric Measurement System QDec

• Automatic production quality assurance of concentrator mirrors with QDec
• High-resolution, optical measurement system based on deflectometry
• Including evaluation and assessment software (failed/passed) to optimize and document production quality
QDec Deflectometric Measurement System
Quality Control in Mirror and Module Production

• Automatic production quality assurance of concentrator mirrors with QDec
• High-resolution, optical measurement system based on deflectometry
• Including evaluation and assessment software (fail/pass) to optimize and document production quality
Trough Modules Shape Measurement in Field with Deflectometry

Slope Deviation in mrad

Local Intercept Factor in %
Measurement Set-up Heliostat Field Deflectometry
Measurement pictures
Deflectometry on Heliostats
Heliostat Shape (measured with deflectometry)

Difference of helio Helio_AA35 to ideal shape [mm]
(differences are displayed with vertical exaggeration)
What is the use of all the data?

- Ray-tracing analyses
- Intercept factor calculations
- Conclusions from achieved accuracy
  - Prediction of performance
  - Specifications for component geometry
  - Analysis of mechanical loads by dead weight, by wind
- Prototype evaluations
- Solar field evaluations
- Quality control systems
  - Mirror product specifications
  - Collector assembly accuracy
Towards standardization of mirror shape analysis
SolarPACES Task III
Guideline on Mirror Shape (MSG)

- draft guideline for measurement of concentrator mirror shape under laboratory conditions
  - include different measurement technologies
  - different mirror geometries
  - introduce the relevant measurement configurations
  - evaluation criteria and formula

- extension of the scope to collectors under field conditions
  - transfer the same criteria and quality parameters
  - draft specifications

- Next meeting September 2013 (Solarpaces Conference USA)
Summary Reflector Shape

• Different measurement techniques available
  • Contact free methods are advantageous: Laser reflection, target reflection

• Shape evaluation in terms of slope (maps)
  • Shape evaluation in terms of focus deviation (maps)

• Evaluation of distribution functions
  • Root-Mean-Square of Deviation Distribution (FDx)
  • Product specific, system specific

• Use Focus Deviation FDx for Specs and Quality control
  • e.g.: FDx ≈ 8-10 mm for EuroTrough with 70mm-receiver

• Use SDx (Slope Deviation) to describe component property
  • Apply to Heliostats and Dishes accordingly (flux is more critical)