The SETScan Patternator

An Overview

En’Urga Inc.
1201 Cumberland Avenue, Suite R, West Lafayette, IN 47906

765-497-3269

http://www.enurga.com

innovations in quality control
Outline

- Background on optical tomography
- Sample applications such as spray diagnostics
- Quality assurance using optical patternator
Background on Optical Patternation

En’Urga Inc.
ininnovations in quality control

SETscan®
Why Optical Patternation?

Purpose: Obtain a cross-section profile of materials

- Fast, capable of obtaining transient data
- Greater reproducibility than mechanical devices because no moving parts
- No interference with the spray
- Greater spatial resolution
- Low maintenance and operational cost
Principal Types of Optical Patternators

- Laser sheet imaging
- Planar Laser Induced Fluorescence
- Extinction based systems (SETscan)
Laser Sheet Imaging

- Laser sheet to illuminate spray
- Image taken using a CCD camera at an oblique angle
- Intensity proportional to drop surface area per unit volume

Potential Errors

- Laser extinction
- Signal attenuation
- Secondary emission  
  Source: Brown et al., ILASS - 2003

Implication: Difficult to get for quantitative patternation

En’Urga Inc.  innovations in quality control

SETscan®
Planar Laser Induced Fluorescence

- Excited with laser sheet
- Fluorescence observed with CCD array
- Intensity proportional to fuel volume fraction

**Potential Errors**
- Laser extinction
- Signal attenuation
- Shot-to-shot variation

Source: Pastor et al., Opt. Express, 2002
The SETscan Patternator (Extinction Based)
Example Spray in Laser Sheet

Hollow Cone
Aircraft Engine
Nozzle

Laser Sheet

innovations in quality control
What is Tomography?

- Tomography means “a picture of a plane.”

Cross-section plane of a human abdomen

FIGURE 25-13
Computed tomography image. This CT slice is of a human abdomen, at the level of the navel. Many organs are visible, such as the (L) Liver, (K) Kidney, (A) Aorta, (S) Spine, and (C) Cyst covering the right kidney. CT can visualize internal anatomy far better than conventional medical x-rays.
Primer on Tomography

Most successful medical diagnostic tool!

X-ray source

Detector array

Field of interest

θ
Principle of SETscan Operation

- Path integrated extinction of laser sheets
- Minimal noise from scattering due to line detectors
- Multiple view angles for non-axisymmetric turbulent flows
- Multiple slices to obtain high spatial resolution
- Local extinction coefficients obtained by statistical tomography (MLE method)
- For liquid sprays, the local extinction coefficient is equal to the drop surface areas per unit volume
Performance Highlights

- Fast Data Acquisition ⇒ Up to 10,000 Hz, transient patternation of fuel injector sprays
- Extinction ⇒ Well developed technique
- Maximum Likelihood Extinction MLE Deconvolution ⇒ Accurate (+/- 2%), Fast (~2 seconds)
- High repeatability (+/- 2% on patternation number)
- Six-axis ⇒ Angular resolution up to 5 degrees
- 512 element array ⇒ Spatial resolution up to 0.2 mm
Basic Information for Quality Control

Mean, RMS, and RMS/Mean of drop surface areas to look at different aspects (uniformity, steadiness, drop size variations, presence of streaks and voids) of the spray

En’Urga Inc. innovations in quality control
Why Surface Area Density?

- Total amount of fuel or liquid evaporated is proportional to heat release rate in combustion and solid mass fraction in spray drying.
- Statistical Correlation coefficient (R) of different parameters with total fuel evaporated:
  - Mass flux $R = 0.903$
  - Diameter $= 0.681$
  - Velocity $R = -0.239$
  - Surface area density $= 0.961$

For combustion, spray drying, and urea dosing applications, surface area density is optimal method of comparing different nozzles or checking uniformity.
Comparison with Competitive Technology

SETscan Advantages:

- Extinction ⇒ Immune to environmental lighting
- Diode lasers ⇒ Class II, No safety issues
- Monolithic ⇒ Out-of-box factory floor deployment
- Adaptive grids ⇒ Alignment of nozzle not critical
- Advanced GUI ⇒ Easily operated by technician
- Reliable ⇒ 100% quality assurance of nozzles

*Only quantitative (+/- 2% on absolute values, +/- .5% repeatability) patternator on the market*
Sample Applications
Aircraft Engine Nozzle

- Struts signature seen in drop surface area map
- Hollow cone seen as hollow
- Drip from nozzle seen at the center
Interpretation of Data

- The data is the ensemble average of drop surface area per unit volume
- Differs from mechanical patternator (which is time average of mass flux)
- High surface area indicates streaks
- Low surface area indicates voids
- 95% ring typically used for spray angle
## Automotive Injector

<table>
<thead>
<tr>
<th>Mean plume angles (deg.)</th>
<th>% area in plume</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.89</td>
<td>19.32</td>
</tr>
<tr>
<td>5.73</td>
<td>4.69</td>
</tr>
<tr>
<td>11.53</td>
<td>21.71</td>
</tr>
<tr>
<td>10.48</td>
<td>17.91</td>
</tr>
<tr>
<td>11.51</td>
<td>23.06</td>
</tr>
<tr>
<td>9.35</td>
<td>12.93</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean centroid (x, mm)</th>
<th>Mean centroid (y, mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.26</td>
<td>-5.69</td>
</tr>
<tr>
<td>-4.84</td>
<td>14.28</td>
</tr>
<tr>
<td>-22.13</td>
<td>1.97</td>
</tr>
<tr>
<td>-29.04</td>
<td>-10.75</td>
</tr>
<tr>
<td>-15.37</td>
<td>-18.49</td>
</tr>
<tr>
<td>0.10</td>
<td>-20.01</td>
</tr>
</tbody>
</table>

**Reliable data with multiple orifice injectors**

*En’Urga Inc.*

Innovations in quality control
Flat Fan Paint Nozzle

Distance from laser sheets

Distance (mm)

3.5"

4.0"

4.5"

innovations in quality control
Quality Assurance of Nozzles
Quality Control Objectives

- Define QC parameters
- Set tolerance limits
- Generate master template
- Compare each nozzle with master template
- Accept/reject nozzle based on patternation result

innovations in quality control
Quality audit configuration

- Control Panel PC
- Ethernet switch
- Ethernet/Serial converter
- Patternator PC
- SQL database PC
- Data cable
- Optical Patternator
- Spray gun

Innovations in quality control
Product Quality Implications

- On-line 100% inspection of nozzles enabled
- Traceable and warehoused data
- Quick design verification tool
- Sorting of already manufactured nozzles
- Can provide Summary Report which includes Major Angle, deviation from center, unsteadiness, Y-integral, Custom parameters
Sample QC parameter (1): Spray Angle

Integrate in concentric circles, each of larger radius, until 95% of Spray Surface Area Density is found.

Angle = 2*(\tan^{-1}(R/X))

En’Urga Inc.  
innovations in quality control
Sample Installation (OP-600)

- 2 computer QA system
- Automatic nozzle mounts
- Booth by Alsmatik
- QA software by En’Urga
- Multiple types of nozzles
- Typical output: 1000/day

Photograph: Courtesy Danfoss S/A

En’Urga Inc. innovations in quality control
## Selected Patternator Customers

<table>
<thead>
<tr>
<th>Customer</th>
<th>Customer</th>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbott</td>
<td>General Motors</td>
<td>Hitachi</td>
</tr>
<tr>
<td>Bend Research</td>
<td>Cummins</td>
<td>AVL</td>
</tr>
<tr>
<td>Pfizer</td>
<td>Emcom Technologies</td>
<td>FEV</td>
</tr>
<tr>
<td>S.C. Johnson &amp; Son</td>
<td>Faurecia</td>
<td>Nordson</td>
</tr>
<tr>
<td>Catalytica Energy</td>
<td>Donaldson</td>
<td>Delavan</td>
</tr>
<tr>
<td>Delphi</td>
<td>Proctor &amp; Gamble</td>
<td>Woodward</td>
</tr>
<tr>
<td>Ricardo</td>
<td>Honeywell</td>
<td>Tenneco</td>
</tr>
<tr>
<td>Continental</td>
<td>Bombardier</td>
<td>Synerject</td>
</tr>
<tr>
<td>Eaton</td>
<td>Rolls Royce</td>
<td>Danfoss</td>
</tr>
<tr>
<td>Columbian Chemical</td>
<td>General Electric</td>
<td>Boston Scientific</td>
</tr>
<tr>
<td>United Technologies Aerospace System</td>
<td>Dow Agrosciences Laboratories</td>
<td>Vertex Pharmaceuticals</td>
</tr>
<tr>
<td>Toyota</td>
<td>Bosch LLC.</td>
<td>3M</td>
</tr>
</tbody>
</table>
Any Questions?
Sample QC Parameter (3): Radial Uniformity

- **Maximum distance**
  \[ \Delta X_{\text{Max}} = \left| S^i_t - S^i_m \right| \]

- **L2 Norm**
  \[ L_2 = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (S^i_t - S^i_m)^2} \]
Sample QC parameter (2): Angular Distribution

- **Maximum distance**
  \[ \Delta \Gamma_{\text{Max}} = \left| S_t^i - S_m^i \right| \]

- **L2 Norm**
  \[ L_2 = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (S_t^i - S_m^i)^2} \]
Sample Report Generated by SETscan

Optical Patternation Report

Contour Plot

Radial distribution plot

Angular distribution plot

Master template limits:
1. Angle: A1 - A2
2. L2 Norm Radial: B1 - B2
3. L2 Norm Axial: C1 - C2
4. Deviation angle: D1 - D2
5. Max. radial distance: E1 - E2
6. Max. axial distance: F1 - F2
7. Total surface area: G1 - G2

Measured values:
1. Angle: A
2. L2 Norm Radial: B
3. L2 Norm Axial: C
4. Deviation angle: D
5. Max. radial distance: E
6. Max. axial distance: F
7. Total surface area: G

Standard nozzle report

Code No:
Operator No:
Nozzle No:
Date:

SETScan OP-600 patternator

En’Urga Inc.
http://www.enurga.com

En’Urga Inc.
innovations in quality control
Selected Customer Comments

“We purchased the patternator and in six months we approached our customer with a request to tighten tolerances on the nozzles we produce”

“The SETscan patternator has given us an order of magnitude return on investment within one year after we purchased it”

“The first time I saw the patternation results obtained with our nozzles on the SETscan, I was amazed. I did not realize what was possible with current technology”

“Our department will most probably win the improved productivity award of our company, thanks in a large measure to the SETscan patternator”