An Overview

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http://www.enurga.com
Outline

- Background on patternation
- Sample applications
- Quality assurance using the SETscan optical patternator
Background on Patternation
Principal Types of Patternators

- Mechanical patternators
- Laser sheet imaging (optical)
- Planar Laser Induced Fluorescence (optical)
- Extinction based systems (optical)
Mechanical Patternator

- Mechanical patternators are placed in the path of the spray with collection tubes.
- In the radial patternators, a set of tubes are arranged in a hemispherical pattern.
- In the circumferential patternators, a set radial lines to delineate the sectors.
- In general purposed patternator, an array of tubes used to get mass flux pattern.

Stagnation plane leads to very low accuracy (~30%)
Worse for high speed sprays from fuel injectors.
Why Optical Patternation

- Fast, capable of obtaining transient data
- Greater reproducibility than mechanical devices
- Does not interfere with the spray
- Greater spatial resolution
- Low maintenance and operational cost
- Ideal for quality audit
- No spray interference or material wastage
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 (less bright on the right)
- Signal attenuation (less light from the back end)
- Secondary emission (multiple scattering from large aperture)

Implication: Difficult to get for quantitative patternation
Planar Laser Induced Fluorescence

- Excited with laser sheet
- Fluorescence observed with CCD array
- Intensity proportional to fuel volume fraction
- Needs fluorophore (dye)

**Potential Errors**

- Laser extinction
- Signal attenuation
- Shot-to-shot variation
- Not used for quality audit
The SETScan Patternator

Spray cross-section

Laser

Laser sheet

Array detector

Only quantitative optical patternator in the market
US Patent No. 6,184,989
Principle of Operation

- Path integrated extinction of laser sheets
- Multiple view angles for non-axisymmetric turbulent flows
- Multiple slices to obtain high spatial resolution
- High speed (10 KHz) for transient patternation
- Local extinction coefficients obtained by statistical tomography (MLE method)
- For liquid sprays, the local extinction coefficients is equal to the drop surface areas per unit volume
Primer on Tomography

Most successful medical diagnostic tool!

- X-ray source
- Detector array
- Field of interest

θ
Performance Highlights

- Fast ⇒ 10,000 Hz, transient patternation of fuel injector and high speed sprays
- Extinction ⇒ Well developed technique
- MLE Deconvolution ⇒ Accurate (+/- 2%)
- High repeatability (+/- 2% on patternation number and +/- 0.5 % on drop surface areas and plume angles)
- Six-axis ⇒ Angular resolution up to 5 degrees
- 512 element array ⇒ Spatial resolution up to 0.2 mm
- Immune to factory floor lighting
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
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.
- Correlation coefficient (R) of different parameters with total fuel evaporated
  - Mass flux $R = 0.903$  Velocity $R = -0.239$
  - Diameter $= 0.681$  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

- 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
- Low power ⇒ Extended life in continuous operation
- Service contracts ⇒ Very short downtime in production
- 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 the drop surface area map
- Hollow cone spray seen as hollow
- Drip from nozzle seen at the center
- Good for high flow rate nozzles (greater than 300 kg/hr)
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.
- 50 to 95% of total enclosed surface areas typically used for defining spray angles.
- Both inner and outer cone angles as well as deviation angles used for quality audit of hollow cone nozzles.
### Automotive Injector

<table>
<thead>
<tr>
<th>Mean plume angles (deg.)</th>
<th>% area in plume</th>
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<tr>
<td>10.89</td>
<td>19.32</td>
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<tr>
<td>5.73</td>
<td>4.69</td>
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<tr>
<td>11.53</td>
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<td>11.51</td>
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<td>9.35</td>
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<table>
<thead>
<tr>
<th>Mean centroid (x, mm)</th>
<th>Mean centroid (y, mm)</th>
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<tbody>
<tr>
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<td>-18.49</td>
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<tr>
<td>0.10</td>
<td>-20.01</td>
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</table>

Reliable data with multiple plume injectors (GDI, shower heads, diesel, agricultural, etc.)
Flat Fan Paint Nozzle

Summary report
Major and minor angles
Deviation from center
Unsteadiness
Y-Integral
Roll, Yaw, Pitch, Aim, and Fan angles
Spray thickness

Used for quantifying wear on nozzles
Sample spray patterns

Agriculture
Pesticide
GDI

Showerhead
PFI
Consumer

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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
- Typical data collection time of 5 second and analysis time of 3 second with the SETscan optical patternator
- Complete thousands of nozzles per 8 hour shift
Sample QC parameter: Spray Angle (s)

Nozzle

Measurement plane

Major, Minor, Inner, Outer, Roll, Yaw, Pitch, Aim, and Fan angles
Sample QC parameter: Angular Distribution

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

- **L2 Norm**
  \[ L_2 = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (S^i_t - S^i_m)^2} \]
Sample QC Parameter Radial Uniformity

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

- **L2 Norm**
  \[ L_2 = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (S_t^i - S_m^i)^2} \]
Example configuration with three computers. All functions performed by the three computers can also be implemented on a single computer.
Sample Report Generated by SETscan

- Sample Report Generated by SETscan

- Optical Pattern Report
  - Patternation Plot
  - Radial distribution plot
  - Contour Plot
  - Angular distribution plot

- Master template limits:
  1. Angle: A1 - A2
  2. L2 Norm Radial: E1 - E2
  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

- Standard nozzle report
  - Code No.
  - Operator No.
  - Nozzle No.
  - Date:

- Skidscan OP-600® patternator
  - En’Urga Inc.
  - http://www.enurga.com

- En’Urga Inc.
  - Innovations in Quality Control

- SETscan®
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
Product Quality Implications

- On-line 100% inspection of nozzles enabled
- Traceable and warehoused data
- Quick design verification tool
- Sorting of already manufactured nozzles
- Customer see proactive quality conscious vendor
- Eliminates tedious manual testing of nozzles
- Less quality errors than manual testing
Selected Patternator Customers

<table>
<thead>
<tr>
<th>Abbott</th>
<th>General Motors</th>
<th>Hitachi</th>
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<tr>
<td>Bend Research</td>
<td>Cummins</td>
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<td>Laboratories</td>
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<td>Toyota</td>
<td>Bosch LLC.</td>
<td>3M</td>
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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 purchase”

“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”