Optics Surface Quality Solutions: The scratch and dig revolution

Dave Aikens

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Manufacturing Processes

• If you can measure it, you can control it and improve it

• The better the measurement
  • The better the control
  • The more opportunities for improvement
Scratches and digs can be specified by **Visibility or Size**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Scratches</th>
<th>Digs</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIL-PRF-13830</td>
<td>Visibility (brightness) (10, 20, 40, 60 or 80)</td>
<td>Apparent size (5, 10, 20, 40 or 50)</td>
</tr>
<tr>
<td>ISO 10110-7</td>
<td>Size (width) or Visibility (10, 20, 40, 60, or 80)</td>
<td>Size (root area) or Apparent size (5, 10, 20, 40, or 50)</td>
</tr>
<tr>
<td>MIL-C-48497 MIF-F-48616</td>
<td>Size (width) (A, B, C, D, E, F or G)</td>
<td>Size (diameter) (A, B, C, D, E, F, G, or H)</td>
</tr>
<tr>
<td>ANSI OP1.002</td>
<td>Visibility (10, 20, 40, 60, 80) or Size (letter)</td>
<td>Size (number or letter)</td>
</tr>
</tbody>
</table>
De Facto Surface Quality Standard:
MIL-PRF-13830

- Specification of “visual appearance of defects on optical parts”
  - Uses a pair of numbers, the first for scratch, the second for dig (e.g., 80-50; 40-10)
  - **Arbitrary numbers** referenced to a set of master scratches and digs
  - Little correlation between the appearance or visibility of a scratch and its measured width. The *shape* of a scratch has a lot to do with its visibility.

Scratch morphology drives brightness
Manufacturing Control: *Scratch and Dig*

Surface imperfections are a significant cause of yield loss

Specified using “scratch and dig” specifications (MIL-PRF-13830B or ANSI OEOSC OP1.002)

- Ways to improve yield loss due to scratch and dig:
  - *Train engineers and technicians* on specifying and measuring scratch and dig
  - *Train manufacturing personnel* on cleaning and handling of optics
  - *Improve inspection process* to reject bad parts and accept good parts
  - *Review rejected parts* to feedback process and/or design improvements
Conventional Inspection

Skilled operator under controlled lighting conditions:

- The trained human eye is quite good (repeatable) in making accurate side by side comparisons.
- Disagreements from inspector to inspector and shop to shop due to differences in:
  - Training
  - Interpretation
  - Illumination
  - Visibility of comparison standards.

Photo from "taking variability out of scratch inspection," presentation to OEOSC by Ari B. Siletz
Where did this specification come from?

Proposed by McLeod and Sherwood from Kodak in 1945

Codified in MIL-O-13830 in 1954;
Current revision is MIL-PRF-13830B

Standard is still in use throughout the industry

- Referenced Drawing C7641866 for the comparison standards
- Current revision of C7641866 is Rev R, and is still based on visual weight, and not width, size, or depth
- Army SOP for preparing comparison samples is based on SavvyInspector® technology at Picatinny Arsenal

You cannot measure the width of a scratch to determine its grade. The scratch and dig evaluation must be done based on brightness.
Myths and Legends

• The scratch number was supposed to be the width in microns
• The Arsenal decreased the scratch width by a factor of 10 in the late 1970’s
• The line width had to be reduced because the scratches “heal” over time
• Artifact standards calibrated in certain years can be used as a functional scratch standard

The truth is that the master scratches and the meaning of the visual appearance of, say, a #40 scratch has been unchanged since the first master scratches were made
Is this Standard Still In Use?

Yes.

The MIL-PRF-13830B standard for “scratch and dig” is still active, and used throughout the optics industry
  • By far the most commonly cited imperfection specification for optics

And

  • The visibility specification is based entirely on MIL-PRF-13830B
  • References the same Military drawing, C7641866, for comparison standards

In 2017, the ISO 10110 drawing standard was revised to add the MIL visibility specification as well

Unfortunately, only the Army has the visibility limit masters, so getting compliant comparison standards has been problematic
The problem with visibility:

Comparison Artifacts

- Only one set of limit standards exist – Picatinny Arsenal
  - This is fine for the Army, but not the rest of us
- Commercial equivalents aren’t always equivalent
  - Davidson Optronics (D-668) uses Army SOP and SavvyInspector® for certification
  - Davidson Optronics (D-667) based on Rev H
  - Brysen Optical (suggested supplier on Army drawing)
  - Jenoptik Paddle – sold by Thor Labs and Edmund Optics

Manufacturers do the best they can to make the sets the same
- Subjective verification of brightness
- No way to correlate set to set

Significant differences exist from make to make
The problem with visibility:

Objective Versus Subjective

• The trained human eye is quite good (repeatable) in making accurate side by side comparisons.

• Disagreements from inspector to inspector and shop to shop due to differences in:
  • Training
  • Interpretation
  • Illumination
  • Visibility of comparison standards.

  ▶ Better training and use of standard hardware helps
  ▶ Ultimately, it is still a subjective measurement

Photo from "taking variability out of scratch inspection," presentation to OEOSC by Ari B. Siletz
Transmitted Light Inspection, Method 1

Ground or opal diffuser with horizontal bars masking 50% of the glass.

To avoid glare, eye may be positioned off-axis.

Element under inspection.

Comparison standard.

40-watt incandescent or 15-watt fluorescent lamp.

75 mm
Transmitted Light Inspection, Method 2

Figure 3 Transmitted Light Inspection, Method 2

40 WATT INCANDESCENT OR 15 WATT FLUORESCENT LAMP

GROUND OR OPAL GLASS

ELEMENT UNDER INSPECTION

MATTE BLACK BACKGROUND

COMPARISON STANDARD
Reflected Light Inspection Setup

Figure 4 Reflected Light Inspection

0.45 m 0.15 m

FIXTURE WITH TWO 15 WATT COOL WHITE FLUORESCENT LAMPS

MATTE BLACK BACKGROUND

ELEMENT UNDER INSPECTION

90°

COMPARISON STANDARD
Reflectance Visibility Measurement

Geometry

from OP1.002:2009

- Illumination with a broad spectrum of angles
- Viewed with a small band of angles
- Part is rotated to achieve maximum visibility

**NOTICE:** This is just an evaluation of integrated scatter for specific angles!
Visual inspection to MIL, ANSI and ISO standards

Transmitted light method 2

Reflected light method
Introducing:
SavvyInspector®

- Same illumination and detection angles
- Illuminates in a ring to eliminate part orientation
- Tailored brightness and integration to make #10 just visible on camera

Diagram: SavvyInspector® recreates the reflection visibility conditions of conventional inspection
Finally Addressing the Subjectivity Problem

Calibrated with any comparison set

Completely objective measurement

The Best Solution for Surface Quality Inspection

Fixed Illumination, Magnification, and Lens Aperture

Designed to match inspection per MIL-PRF-13830B
The SavvyInspector®
Model SIF-8M

Motorized three-axis 200 x 200 x 70
The SavvyInspector®
Model SIL-4

- Part sizes up to 70 mm diameter
- Convex or Concave
- Up to f/2 surface slopes
- Real-time feedback
- Army traceable

Manual x, y, tip-tilt and motorized focus
The Software is the Key

- Scratch window
- Dig window
- Image field
- Scratch or dig value
- Scratch Length
- Active calibration file
- Scratch visibility bar
- Dig size bar
- Inspector window
- Saved data location
- Save data buttons
Army-traceable Visibility Samples

- Completely re-mastered
- Certified using Army SOP
  - SavvyInspector® calibration
OP 1.002 Dimensional Standard

- Based on Annex B of the standard

- A 10x loupe with a fixed reticle is also available
  - Fast, efficient
ISO 10110-7
Comparison Standards

POG Praezisionsoptik Gera GmbH Standards
(comparison plates)

0.040  0.250  0.400

Max Levy
(both positive and negative versions of artifacts)
## Scratch and Dig Inspection Options: Flat Optics

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Solutions for: Scratch and Dig Inspection on Flat Optics

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Savvy Optics contributions:

| Savvy Optics Training | Mapping and Certification with SIF4 | Savvy Optics helps develop and sell | Savvy Optics co-invented – we sell and rent |
# Surface Imperfection: Scratch and Dig on Curved Surfaces

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| Savvy Optics Training                  | Mapping and Certification with SIF₄       | Savvy Optics helps develop and sell          | New Product by Savvy Optics Corp.              |

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Customer Applications of the SavvyInspector®

- 100% inspection of high-value parts
- Categorize imperfections
- “Go”/“No-Go” for volume parts
- Document failed parts
- Surface texture evaluation
- Customer-specific calibrations
- Periodic retraining for floor personnel
- Training for new inspectors
- Autoscan for surface mapping
- Forensics on defect influence on final product

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Customers are using the SavvyInspector® in ways we would never have imagined to improve yield and profit.

- Totally objective “gold standard”
- Very repeatable
- Easy to calibrate
- Easy to operate
- Permanent record and traceability
- Mapping and autoscan

SavvyInspector® takes the subjectivity out of the scratch inspection process.
The leaders of the industry are part of the solution

Welcome to the revolution!