Objective Scratch and Dig Measurements

Dana Takaki and David M. Aikens
Savvy Optics Corp, 35 Gilbert Hill Rd., Chester, CT 06412
dtakaki@savvyoptics.com
daikens@savvyoptics.com

Surface imperfections (i.e. Scratch-Dig) on optics have traditionally been evaluated by trained inspectors who visually compare the surface imperfection on a production part to a surface imperfection on a calibrated standard. The lighting and magnification are carefully specified to improve repeatable results, but at the end of the day, the classification is a subjective opinion of the operator [1]. Finally, the SavvyInspector™ is available to assist the operators by objectively classifying surface imperfections on flat surfaces per MIL-PRF-13830B and documenting the both the image and the data in digital files. This paper discusses the SavvyInspector™ hardware and software and gives examples of measuring a scratch and a dig.

1. Introduction – The scratch standard is only a cosmetic standard [2]

For more than fifty years, the de facto standard method of describing surface quality in optics has been with a pair of numbers referred to as the scratch and dig specification [3]. And for almost as long, people have been trying to use this cosmetic standard to control surface imperfections on precision optics, where scratches and digs affect the performance of the system [4,5]. The result has been confusion and misunderstanding. The scratch and dig specification is a highly subjective visibility standard, which may be adequate for cosmetics, but insufficiently quantitative for performance-based specifications.

The SavvyInspector™ model SIF-4 provides software assisted scratch and dig evaluation of flat optical surfaces, eliminating the subjectivity of human surface quality inspection. The instrument is designed specifically to reproduce the conditions of an in-reflection visual inspection described in Appendix C of MIL-PRF-13830B, "General specification governing the manufacture, assembly, and inspection of optical components for fire control instruments." The factory calibrated inspection head of the SavvyInspector™ uses invariant illumination and detection optics and propriety analysis software, allowing objective, repeatable, and recordable evaluation of scratch-dig surface quality.

2. SavvyInspector™ SIF-4 System Overview

SavvyInspector™ SIF-4 is a complete flat-optics inspection system consisting of:

1. A custom LED-based illumination assembly.
2. A measurement head with a digital high-resolution camera, optics, and light baffling.
3. A manual z-stage.

4. A manual, position encoded 100 mm x-y stage platform with rails for holding parts.
5. Base-stand assembly.
6. A stand-alone computer with proprietary SavvyInspector™ analysis software.
7. Cabling.

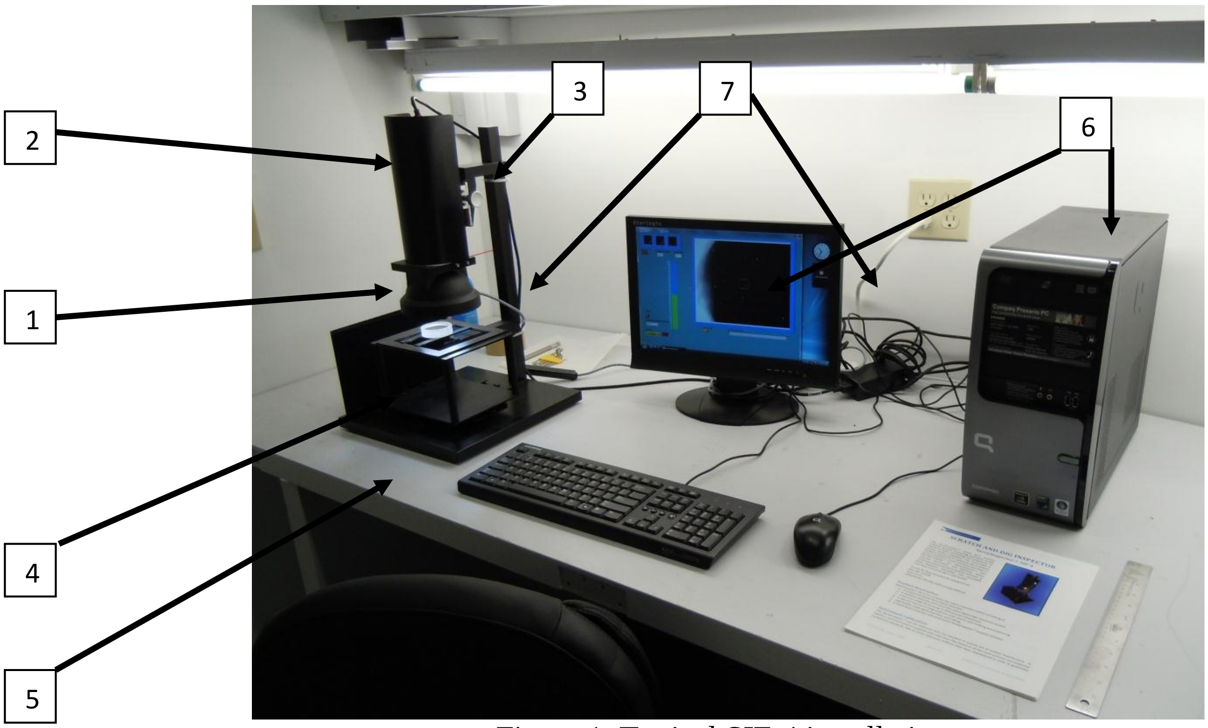


Figure 1. Typical SIF-4 installation.

Software

The proprietary SavvyInspector™ software is the key to software assisted scratch and dig inspection. Figure 2a shows the inspection features, and figure 2b shows the administrative and image field features.

1. Image field
2. Inspection box
3. Raw data box
4. Scratch inspection box
5. Dig inspection box
6. Short scratch Length
7. Scratch value display
8. Dig value display
9. Scratch brightness color bar
10. Calibration pull down menu
11. Scratch Calibration
12. Long scratch length
13. MIL / ISO mode toggle switch
14. Raw scratch value
15. Calibration password field
16. Invert image button
17. Stop button
18. Save image button and image path output
19. Comment field for log entries
20. Write data to log file button and data path
21. Zoom, Select, Drag, and Marker toggle
22. Zoom to fit button

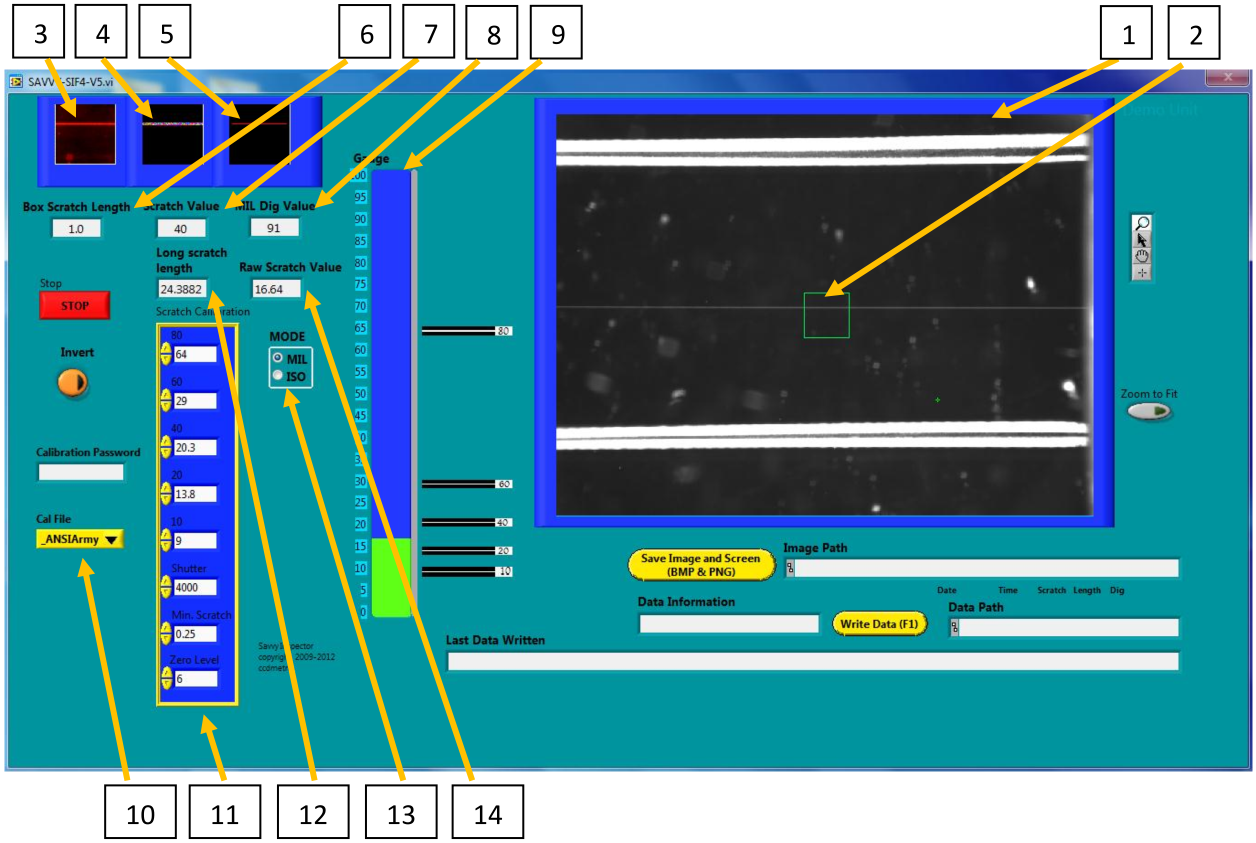
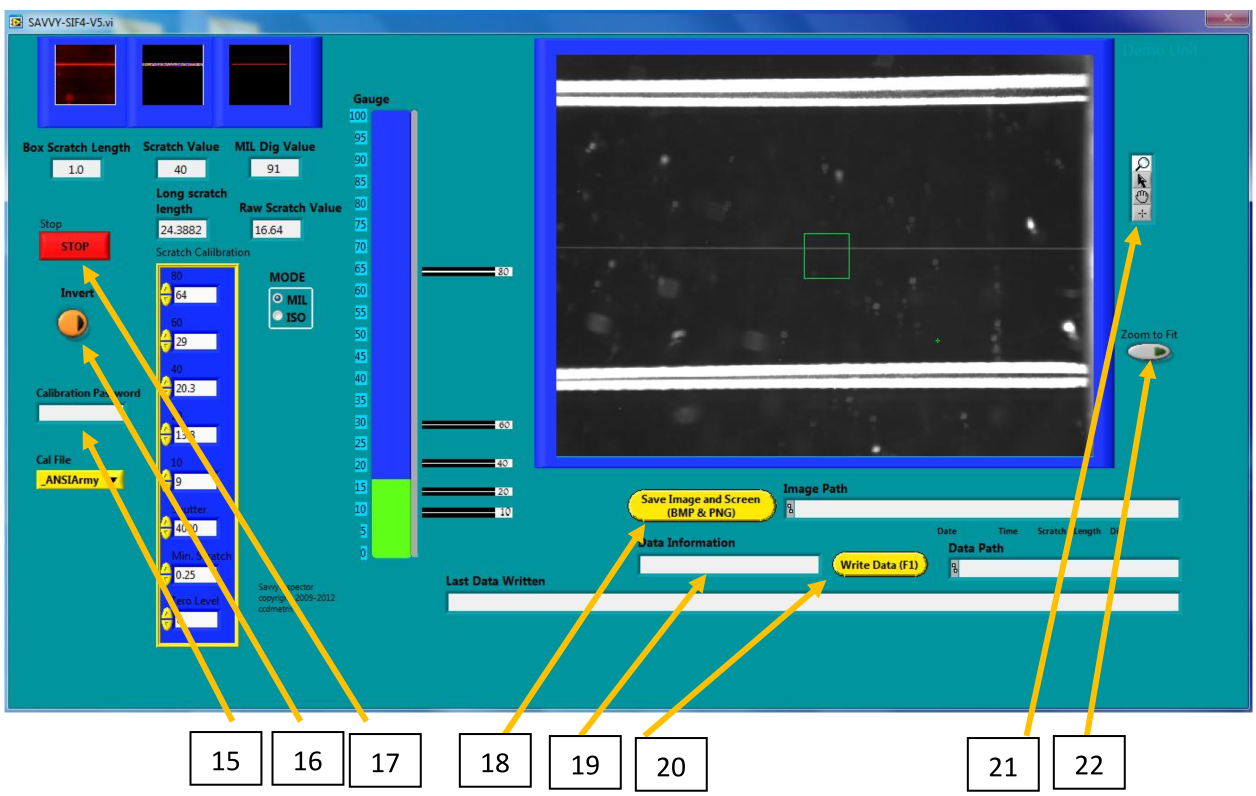


Figure 2a and 2b. Diagram of the Inspection Software Features



Calibration Files

The SavvyInspector™ software comes from the factory with calibration files based on all the most common and respected comparison standards manufactured by FLIR/Brysen, Davidson Optronics, and Jenoptik. Sets of these calibration artifacts have been sequestered in order to guarantee instrument to instrument agreement during the manufacture of each SavvyInspector™. If the user needs a scratch inspection done to a standard which is not in the factory calibrations library, a custom calibration file can be created in the password protected calibration mode. The operator presents the SavvyInspector™ with the desired comparison artifact, and enters the measured visibility into the appropriate data field for that scratch number. The calibration data can then be saved and accessed from the inspection mode.

3. Set Up for Inspecting a Surface using the SavvyInspector™

Prepare the sample

Clean the part to be measured following in house cleaning practices. Visually inspect the sample under a bright light to locate any obvious scratches or digs and note their locations. Re-clean the part with solvents if allowed and appropriate to remove as many scattering sources as possible.

Load the sample

Move the stage as far towards you as possible and shift it to the right end of travel. This is the load position. Put the part between the adjustable stage rails on the inner lip of the rails so the surface to be inspected is flat.

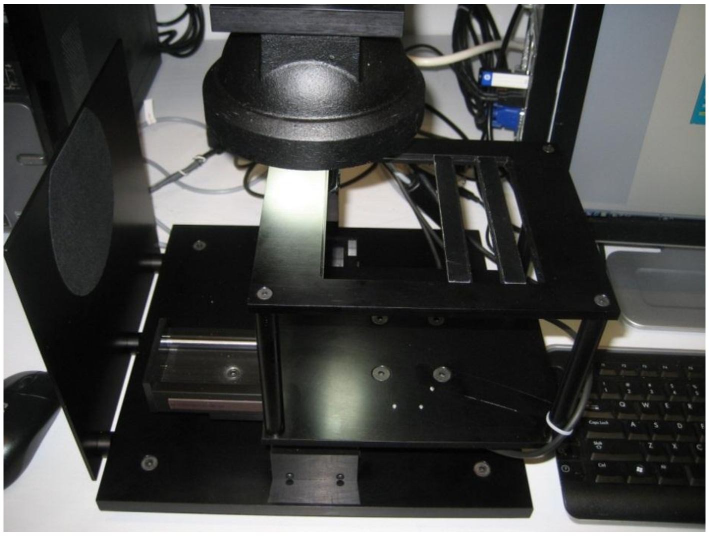


Figure 3. Load position for the stage.

Setting the focus

Once the part or parts are loaded, inspection can begin. Move the stage so that the part to be inspected is beneath the lightsource, and the image field shows that the part is in place. Move to any edge of the part, and check focus. The image should be sharp and clear. If the image is out of focus, rotate the z-focus knob to bring the surface into focus, and then lock the stage with the locking lever. Check focus to confirm that the top surface is in focus, and the image is sharp and clear.

Select desired calibration file

Check the calibration file displayed in the calibration pull-down menu to verify that the desired calibration file has been selected. If the displayed calibration file name is not the one desired, click on the pull-down menu, and select the calibration file desired. Table 1 shows the calibration files which are provided with all instruments and are considered "factory calibrations".

Table 1. Factory calibrations provided.

File Name	File
_ANSI Army V1-12	Software only file based on Army limit standards
_Brysen.sdi	FLIR/Brysen SAD SN 1109 comparison standard
_Davidson.sdi	Davidson D-667A SN 2431 comparison standard
_Dig Mode.sdi	Software file to provide optimum illumination for digs
_EK_Refl.sdi	Eastman Kodak EKCO CM-4 paddle; reflective side
_EKpaddle.sdi	Eastman Kodak EKCO CM-4 paddle; transmissive side
_Jen_Refl.sdi	Jenoptik EO #53-157 CM1 paddle; reflective side
_EON53-157.sdi	Jenoptik EO #53-157 CM3 comparison paddle
Setup.sdi	Cal file used to set up the instrument; not for inspections

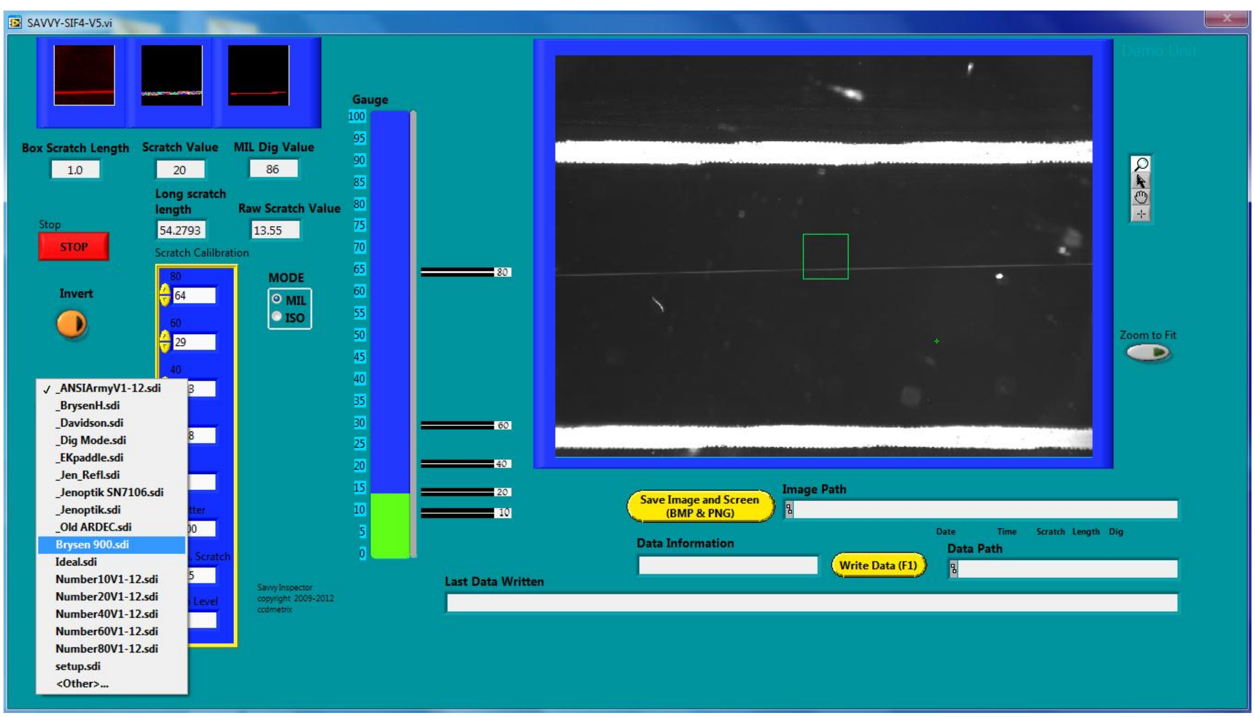


Figure 4.

Clicking on the calibration file button opens the calibration file menu, allowing the user to choose the appropriate calibration file for the component being inspected.

If a new calibration file is needed or desired, one can be created by the tool owner by entering the password protected calibration mode. Additional details are in the Savvy Inspector Manual.

Conduct the inspection

Scratches and Digs must be located by the operator. Use the X-Y stage to move the sample under the camera. Scan the surface for imperfections. Move to each position of interest, so that the imperfection is within the green inspection window in the image field.

4. Determining a Scratch Grade

Use the X-Y stage to move the sample under the camera until the brightest part of the scratch is within the green inspection box in the image field.

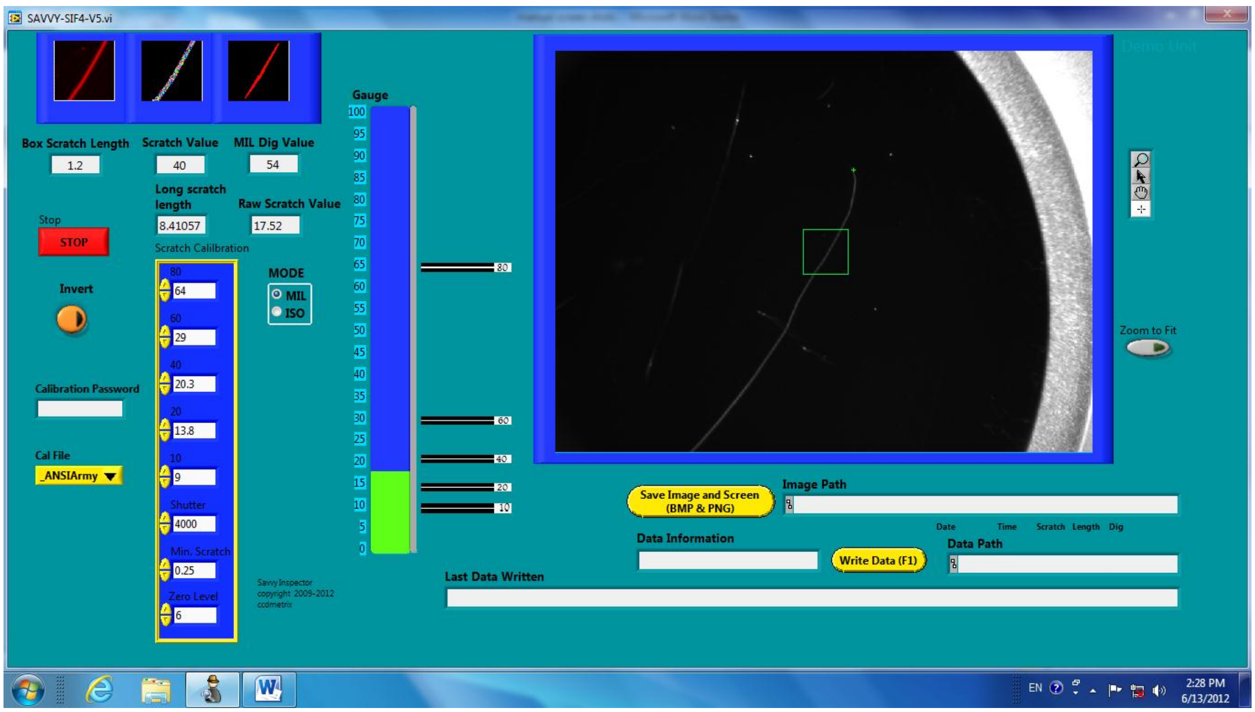


Figure 5. The SavvyInspector™ window during a scratch inspection.

Scratch Brightness

The SavvyInspector™ software is "always on", and provides a continuous assessment of the brightest continuous imperfection within the inspection box. In the upper left corner of the SavvyInspector™ screen, there are three boxes and three data fields. Once a scratch is positioned under the camera and focused, the SavvyInspector™ SIF-4 will report the brightness of the scratch, compared to the calibration file selected in the Cal File menu box.

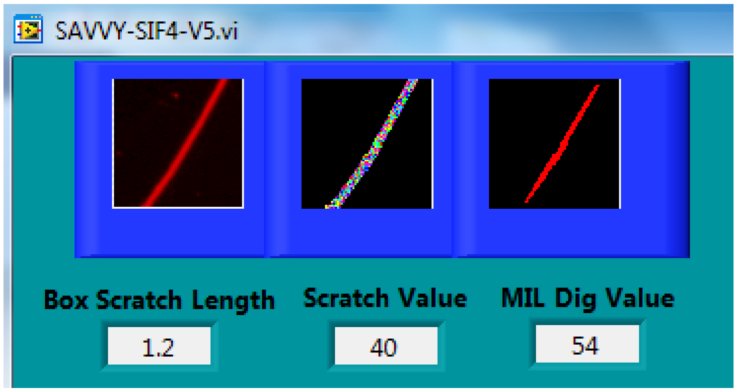


Figure 6. Upper left corner of SavvyInspector™ window during a scratch inspection.

The left-most box is the raw false-color data from the camera. The center box shows the region identified by the software which appears to be a continuous scratch. All other signal has been suppressed, and only the scratch brightness is shown. If this box is flickering or the scratch is "jumping around" then the software is not able to obtain a good reading.

The closest but more visible grade [1] for the highlighted scratch is reported in the scratch brightness field. If the scratch brightness is within the acceptable limits of the calibration file, its value will be either 10, 20, 40, 60 or 80. If the scratch brightness is greater than the greatest allowed scratch in the calibration file, the software reports the scratch brightness as 100. If the scratch brightness is below the zero value in the calibration file, the scratch grade will be zero and the scratch grade box will turn red.

If the scratch is completely contained within the inspection box, the length of the scratch is reported in the "Box Scratch Length" field, in mm. If the scratch extends beyond the edges of the box, the "Box Scratch Length" is reported as 1, and a long scratch length measurement is required.

Measuring a Long Scratch Length

The manual x-y stage has encoders of both axes which feedback the stage position directly into the software. To determine a scratch length, move the stage so that one end of the scratch is visible in the image field. It need not be in the inspection box; anywhere in the image field will do. Select the marker toggle (shown as a +) next to the image field. Position the mouse over the end of the scratch and click the left mouse button to mark the location; a green + will appear on the end of the scratch. Then press the right mouse button to reset the encoders; the long scratch length field will be set to zero. Now translate the stage until the other end of the scratch is positioned at the same +. The value displayed in the long scratch field is the length of the scratch in millimeters, as shown in figure 7.

[1] There are two methods of determining the grade of a scratch which are common practice. One is to select the grade of the scratch which is "closest in visibility" to the scratch being inspected. The other method is to report the grade of the scratch which is "closest but more visible" than the scratch being inspected. There is no consensus on the correct method to interpret MIL-PRF-13830B, however the American National Standard ANSI/OEOSC OP1.002, which is based on MIL-PRF-13830B, requires use of the "closest but more visible" grade level method.

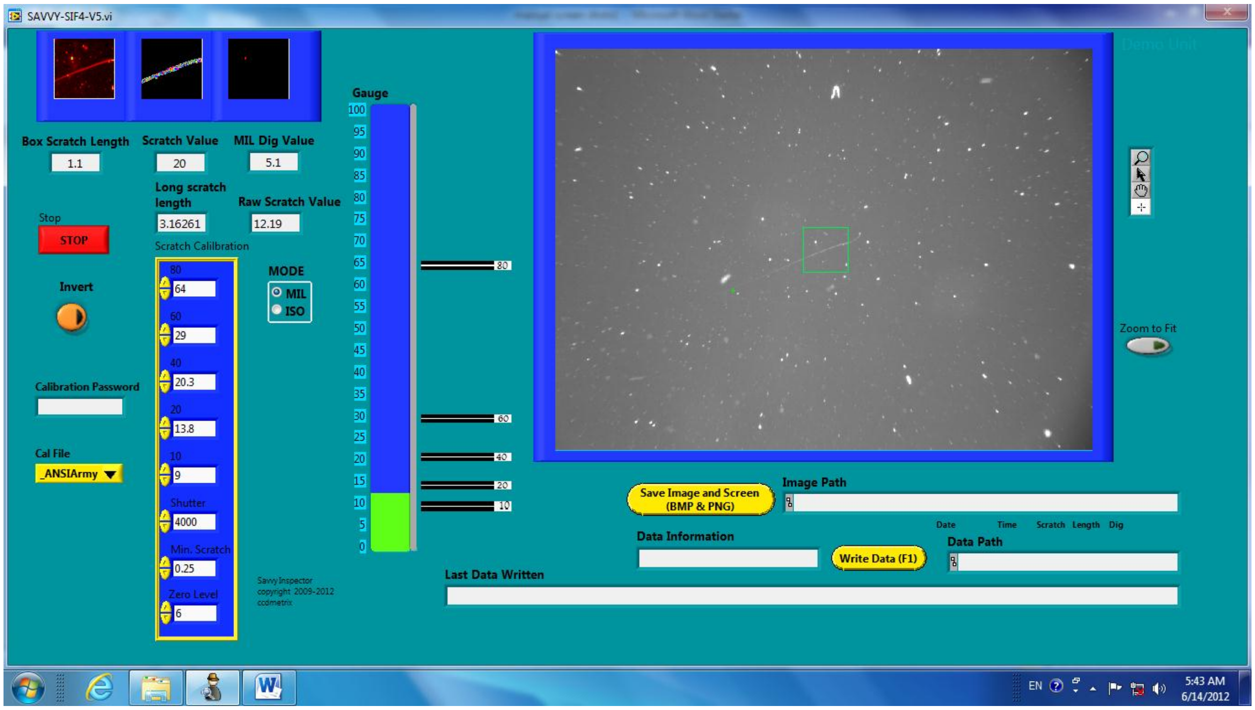


Figure 7. When the stage is translated, the Long scratch length box reports the total motion of the stage. When the ends of the scratch are used for the start and end of the translation, the result is the length of the scratch; in this case 3.16mm.

Scratch Brightness Bar

For rapid assessment of maximum allowable scratch, the scratch brightness color bar is provided. The scratch brightness bar shows the brightness of the given scratch in arbitrary units on a scale from 0 to 100. The bar is green as long as the scratch value is less than the maximum brightness allowed for a #80 scratch. If the scratch is brighter than a #80, the bar turns red. Such a scratch is always cause for rejection of the part. The relative intensity for the given calibration file is reported next to the scratch brightness color bar for a quick visual assessment of a given scratch.

Document the Scratch

Record the location, lengths and brightness value of the scratch. If desired, click the “save image” button to create a permanent image file of the scratch, and/or the “write data” button to create a new line in the log file for the scratch.

Record the data

If a record of an inspection image is desired, click the “Save Image” button before proceeding to the next measurement. “Save Image” files are placed in the SIF “Data” folder, as indicated in the image path. All images are date and time stamped for easy identification.

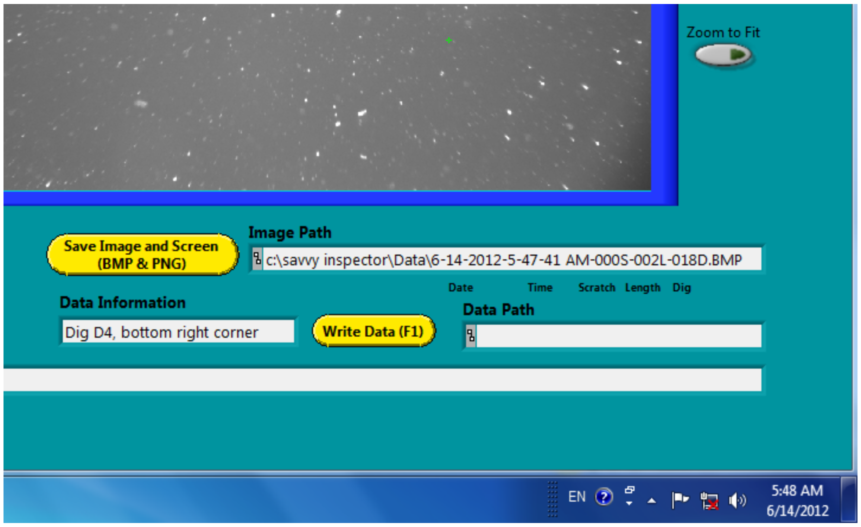


Figure 8. Pressing the "Save Image and Screen" button stores the screen shot and image data into the image path noted at the right.

In addition, data can be exported to a .CSV file via the write data button. A comment of any length can be typed into the data information field, to identify the surface and/or the imperfection to be recorded. The write data button exports this comment, along with the scratch grade, dig grade, scratch length (if any) and calibration data. The log file is located in the SIF "Data" folder, as indicated in the data path. Pressing the write data button creates a new entry into the log file for the current inspection, including the text in the Data Information box. The log file location is noted in the Data Path box.

5. Measuring a Dig

Digs must be located by the operator. Use the X-Y stage to move the sample under the camera until the desired dig is within the green inspection box in the image field. The software will continuously report the size of the maximum dig within the inspection box. The dig need not be centered; in fact, when measuring a small dig which is close to a large dig, it will be necessary to shift the image until the larger dig is not in the inspection box.

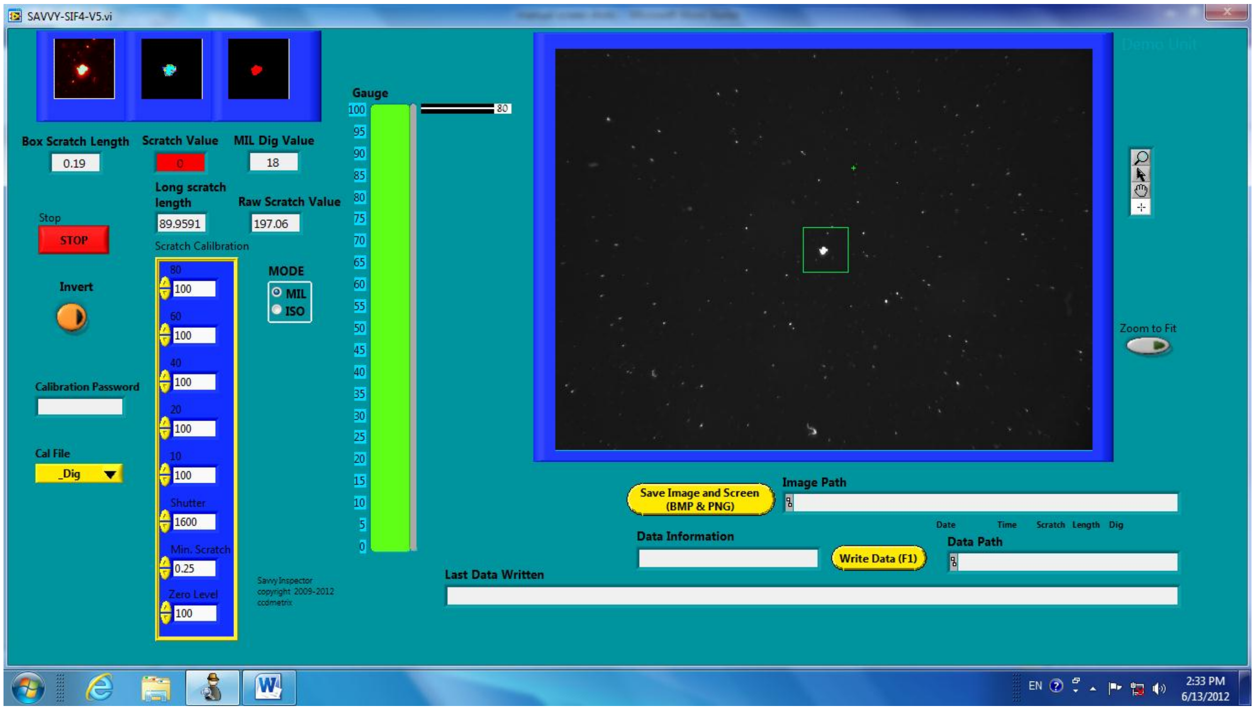


Figure 9. The SavvyInspector™ window during a dig inspection.

Dig Value

Once a dig is positioned under the camera and focused, the SavvyInspector™ SIF-4 will report size of the dig in units of tens of microns. That is, a dig which is 200 microns in diameter is reported as a #20, while a dig which is 400 microns would be reported as a #40, and so on.

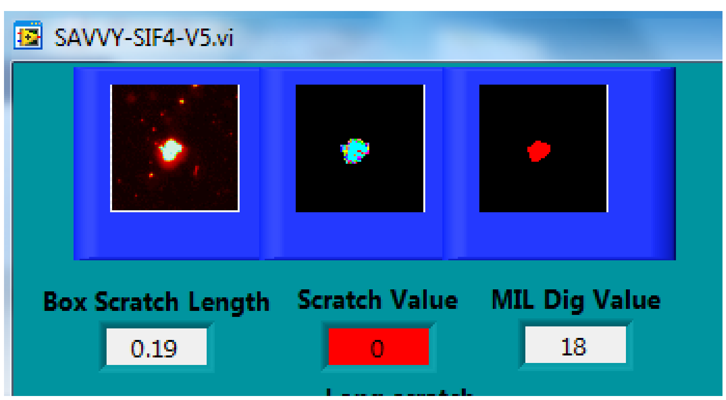


Figure 10. Upper left corner of SavvyInspector™ window during a dig inspection.

The left-most box is the raw false-color data from the camera. The right-most box in the upper left corner of the screen shows the edges of the largest dig-like feature on the surface within the inspection box. All other signal has been suppressed, and only the dig perimeter is shown. If this box is flickering or the dig is "jumping around" then the software is not able to obtain a good reading.

Note that there are two different methods of grading digs. A strict interpretation of the MIL-PRF-13830B or the American National Standard ANSI/OEOSC OP1.002 [6] requires that all digs be reported in units of 10 microns, so that a dig which was 210 microns would be a 21, a dig which was 320 microns would be a 32 and so on. Practically speaking, however, the dig inspection is one of "apparent size", and the inspection is to be done based on the visual appearance of the dig compared to a dig artifact set. This has resulted in a different interpretation, in which digs are measured in terms of the closest grade. That is, a 210 micron dig would be a #20, and the 320 micron dig would be a #40, since there is no #30 dig grade.

In order to allow the greatest flexibility, the SavvyInspector™ software reports the dig values in the dig field in units of tens of microns, without rounding to the nearest grade. If grading is desired, it is up to the user to do the rounding.

Irregular Digs

The dig evaluation of the SavvyInspector™ software is making a trace of the edge of the dig and evaluating its size based on this edge profile. For a circular dig, the dig value is simply the diameter of the dig. However for irregular digs, the value reported is the circle of equivalent area. This makes allowance for the fact that image analysis is not perfect, and that most digs are indeed circular in shape.

The MIL-PRF-13830B and ANS ANSI/OEOSC OP1.002 standards allow for "irregular digs" to be assessed as ½ the maximum length times the width. No definition is provided for "irregular", so this provision is difficult to interpret. Such a measurement, moreover, is not repeatable due to the subjective nature of the "maximum length and width". The method of the "circle of equivalent area" is common practice, and is slightly pessimistic for irregular digs. Since it also results in a more repeatable measurement, we have elected to always report dig grades according to their circle of equivalent area, and ignore the "irregular digs" provision of MIL-PRF-13830B.

Document the Dig

If desired, click the "Save Image" button to create a permanent image file of the dig and/or the "Write Data" button to create a new line in the log file.

6. Conclusion

The visibility standard for surface imperfections is here to stay. While it can be challenging to determine a meaningful scratch-dig specification, it is the de facto standard method for specifying optics surface quality [7]. The biggest challenge is the subjectivity of a visibility test. The SIF4 replaces the subjectivity of the operator for classifying the defects. Once the operator locates the imperfections, it takes a few seconds more to move to the position where the biggest imperfection is, get a grade, and store the data and image. If there are only three or four imperfections, a part can be inspected and all the imperfection images grabbed in much less than a minute. SavvyInspector™ customers tell us that the SIF4 has big advantages over the subjectivity of an experienced inspector. This system will document the defect with an image and scratch-dig numbers. This is usually preferred to the operators' eyes and operators' notes. An experienced operator will usually get the same number as the SIF4, but the screen shot and objective measure is better for documentation and communication.

Although there are no formal studies, our customers report that the SIF is more repeatable than an experienced inspector using a light source, magnification and comparison calibration standards. Different operators will get the same measurement for the same defect, even if the operators have different levels of experience. The inspectors using the SIF4 like the system because it makes their job more fact and less judgment. This is especially true for scratches.

Sometimes inspectors err on the side of caution and reject good parts if there are any visible defects. The SIF gives them confidence to accept good parts with visible imperfections that are below the scratch-dig threshold.

7. References and notes.

[1] D. M. Aikens, "The truth about scratch and dig," *Optical Fabrication and Testing*, OTuA2 (OSA, 2010)

[2] M. Young, "The scratch standard is only a cosmetic standard," Proc. SPIE Vol 1164, pp185-190 (1989).

[3] J.H. McLeod and W.T. Sherwood, "A proposed method of specifying appearance defects on optical parts," J. Opt. Soc. Am. Vol 35, pp 136-138 (1945).

[4] M. Young, "Can you describe optical surface quality with one or two numbers?" Proc SPIE 406, pp 12-22 (1983).

[5] R. E. Fischer, "An interview with Matt Young on the scratch and dig standard for optics," OE Reports, Vol 44 (1987).

[6] ANSI/OEOSC OP1.002-2009, "American National Standard For Optics and Electro-Optical Instruments-Optical Elements and Assemblies-Appearance Imperfections." American National Standards Institute, Inc. (2009).

[7] D. M. Aikens, "Meaningful surface roughness and quality tolerances", in International Optical Design Conference 2010, Proc. SPIE Vol. 7652 (2010), 765217.

About Dana Takaki:

Dana Takaki's interest in optics began when she was a student at MIT and was hired by IBM to spend a summer bringing up the first WYKO3D optical profiler. She finished her BS in mechanical engineering at MIT and followed up with a MS in mechanical engineering from UC Berkeley. She worked for 15 years in semiconductor capital equipment (KLA, Lam, Thermawave) as a manufacturing engineering and new product manager. More recently she consulted with Cambridge Collaborative Inc. as an acoustic engineer before taking on a role in Savvy Optics in Manufacturing, Sales and Marketing. Dana also plays violin professionally with local orchestras and bands.

About Dave Aikens:

In addition to teaching and consulting, Dave Aikens serves as head of the American delegation to ISO TC 172 and the Executive Director of the Optics and Electro-Optics Standards Council. It is both a professional and personal goal of his to improve the quality and understanding of optics standards in the industry. He has been teaching the Scratch Dig class for several years and the total number of participants is over 1000 people including engineers, inspectors, sales and marketing. The ISO class has been offered several times and targets those who either design their own optics, work with optical designers, or manufacture optics to ISO 10110 tolerances. The newest class, Making Sense of Waviness and Roughness on Optics, demystifies the annoying Mid Spatial Frequency Ripple that he first studied at Lawrence Livermore Lab and is becoming of great interest to the community with the advent of deterministic polishing. Dave Aikens is the co-inventor of the Savvy Inspector. Savvy Optics builds the Savvy Inspector in CA and CT and supports sales in the US. The Savvy Optics also sells through distributors in England and Japan.

Savvy Optics Video Link for You Tube: http://youtu.be/ib9sE83m9cA