Proc. of SPIE Vol. 0181, Contemporary Optical Systems & Components Specifications, ed. Robert E. Fischer (Apr 1979) Copyright SPIE

Performance impact of cosmetic defects on mass-produced photographic optics

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Abstract

The effects of cosmetic defects such as scratches and digs as well as surface cleanliness are seen as increased veiling glare. Veiling glare lowers the contrast transfer function of camera objectives. Simplifying assumptions allow this effect to be estimated. Experimental data indicate that surface quality standards required for cosmetic reasons are higher than might be imposed for the purpose of maintaining image quality.

Introduction

Cosmetic defects are those imperfections which can be observed by looking at a lens. Scratches, digs, bubbles, inclusions, coating flaws, dust, lint, dirt, and residue from cleaning could all be classified as cosmetic defects. The question of how cosmetic defects affect image quality is probably as old as the subject of image analysis. As Maccabee and Grover(1) pointed out in their paper delivered at the SPIE conference in 1977, there isn't much in the open literature relating to a theoretical development of the problem. The problem is one of relating stray light and image contrast.

Stray light can arise from many sources. In photo objectives there are several major classes of stray light. First, and probably the most dramatic, is multiple specular reflection from optical surfaces. This produces ghost images in the image plane to the great delight of television ad-men and cinematographers. In a similar but distinct category are bright rings and other local "hot spots" caused by highly directional reflection from retainers, spacers, internal barrel surfaces, and the edges of lenses. The sort of stray light generally refered to as veiling glare is much less localized in the image plane. One common cause of this veil of stray light is by way of reflection from an optical surface in the rear of a lens assembly more-or-less concentrating light on the leaves or a stopped-down iris diaphragm. The iris then becomes a secondary source illuminating the image plane. Finally, there is stray light scattered by cosmetic defects.

A common method of measuring stray light in photo objectives is the one defined in MIL-STD-150A (1959) for veiling glare. This method, following from the work of Goldberg(2) in the 1920's, and Coleman(3) and Kuwabara(4) in the 1950's, is by definition an axial measurement and as such may not adequately detect the presence of certain types of ghosts and rings. However, since it is a widely used method and does relate to previously reported data(3), there is good reason to utilize this type of test. In the context of this investigation the MIL-standard test(5) is probably the best one to quantify the effects of veiling glare arising from cosmetic defects.

A comprehensive model of stray light or even veiling glare per se is quite complicated and the effects on image contrast are highly dependent on the distribution of light in the object scene. Without attempting a comprehensive model, this paper will develop approximate relationships by which an estimate of the effects of veiling glare on image contrast can be calculated.

Veiling Glare and Surface Quality

As several authors have reported, the state of surface quality can affect veiling glare measurably. The first question which concerns the producer of photo objectives is, "What is the level of veiling glare produced by cosmetic defects which are marginally acceptable?", and then, if it is detectable, "What is the effect on image quality?"

Veiling glare measurements made at Vivitar on photo objectives which were considered to be marginally acceptable from a cosmetic standpoint did not show any stray light in addition to the level measured on acceptable samples. The experimental error in the apparatus is approximately ± 0.3%. Because marginally acceptable defects are so small, it is very difficult to simulate them in a controlled manner. A controlled experiment was, therefore, not attempted. Several additional tests were performed to investigate the results of defects which would definitely be classified as unacceptable.

One lens was intentionally dirtied with graphite dust with no measurable increase in veiling glare. Another was tested with and without the proverbial thumb print. Veiling glare increased from 1.3% to 1.5% at f/2.3 (within experimental error). The increase at f/22 was from 4.1% to 5.9%.

A lens which had been sitting on a shelf without a lens cap for several years was tested before and after cleaning. On the rear surface there was an awful scum of the sort which can only be collected by a lens in Los Angeles. Veiling glare dropped 2.0% at all apertures after cleaning.

These results can not compare in volume or variety to Coleman's data based on 500,000 readings. They do, however, confirm his basic conclusions as to the relationship between defect size relative to pupil diameter and net effect.

MTF & Veiling Glare

When veiling glare is known, the effect on image contrast can be estimated if certain simplifying assumptions are made. One of the assumptions is that the object field brightness is relatively uniform. Many scenes may satisfy this assumption well enough to use the estimated effects - even if some detail of interest has a brightness quite different from the average. For example, a picture including a well shadowed face surrounded by a rather bright background (where the face is a small fraction of the field of view) would show the effects of veiling glare. These effects may be estimated by the relationships developed in this section.

As Maccabee & Grover discuss in their paper, veiling glare measurements give us the values needed to calculate low frequency contrast transfer. If V is defined as

$$V = \frac{E_{o,g}}{E_{b,g}}, \tag{1}$$

where $E_{o,g}$ is the illuminance of the dark image area in the veiling glare test and $E_{b,g}$ is the illuminance of the bright surrounding area, V is the decimal equivalent of the MIL-STD definition of veiling glare. The subscript g indicates that the illuminance values of the object (o) and background (b) contain some spurious illuminance due to stray light or glare. The contrast transfer of large objects follows directly:

$$CT = \frac{E_{b,g} - E_{o,g}}{E_{b,g} + E_{o,g}} \tag{2}$$

Combining (1) & (2) gives the relationship:

$$CT = \frac{1 - V}{1 + V} \tag{3}$$

By defining the added illuminance due to glare as G and separating this from the unmeasurable values of E_o and E_b, contrast transfer can be expressed as

$$CT = \frac{(E_b + G) - (E_o + G)}{(E_b + G) + (E_o + G)} \tag{4}$$

Ideally $E_o = 0$ and normalizing to $E_b = 1$ equation (1) becomes

$$V = \frac{G}{1 + G} \tag{5}$$

Inverting, G can be expressed as a function of V

$$G = \frac{V}{1 - V} \tag{6}$$

This is useful because we want to express contrast transfer as a function of V (a measurable quantity) and MTF (also measurable).

If the average illuminance of the field of view is different from the average brightness of the detail of interest, equation (4) becomes

$$CT = \frac{(E_b + KG) - (E_o + KG)}{(E_b + KG) + (E_o + KG)} \tag{7}$$

where

$$KG = \frac{KV}{1 - V} \qquad (8)$$

from equation (6).

Combining (7) and (8) yields

$$CT = CR \frac{(1 - V)}{(1 + KV)} \qquad (9)$$

where

$$K = \frac{E_B}{(E_b/2)} - 1 \qquad (10)$$

E_B is the average scene illuminance and $E_b/2$ is the average brightness of the detail of interest. This says that when the average background illuminance is equal to the average illuminance of the region of interest K is zero and

$$CT = CR\ (1 - V) \qquad (11)$$

If the background is twice the average of the detail then K = 1 and so on.

Conclusions

The relationships of equations (9) and (10) allow estimates to be made of the effects of veiling glare on contrast transfer. As an example I shall use some data measured on an actual lens. The following table shows measured MTF (with no appreciable glare), calculated contrast transfer if $E_B/E_b = 0.5$ and if $E_B/E_b = 1.0$

f/2.3 (Veiling Glare = 1.3%)

l/mm	No Veiling Glare	$E_B/E_b = 0.5$	$E_B/E_b = 1.0$
10	.80	.79	.78
20	.66	.65	.64
30	.57	.56	.56
40	.49	.48	.48
50	.41	.40	.40
60	.36	.35	.35

f/4.0 (Veiling Glare = 1.9%)

l/mm	No Veiling Glare	$E_B/E_b = 0.5$	$E_B/E_b = 1.0$
10	.90	.88	.87
20	.78	.77	.75
30	.68	.67	.65
40	.57	.56	.55
50	.48	.47	.46
60	.41	.40	.39

f/8 (Veiling Glare = 2.6%)

l/mm	No Veiling Glare	$E_B/E_b = 0.5$	$E_B/E_b = 1.0$
10	.92	.90	.87
20	.82	.80	.78
30	.67	.67	.66
40	.57	.56	.54
50	.45	.44	.43
60	.37	.38	.37

f/22 (Veiling Glare = 4.1%)

l/mm	No Veiling Glare	E_B/E_b = 0.5	E_B/E_b = 1.0
10	.88	.84	.81
20	.74	.71	.68
30	.58	.56	.53
40	.40	.38	.37
50	.26	.25	.24
60	.14	.13	.13

Thus the estimated effects of veiling glare can be seen to be relatively small at high spatial frequencies. The low frequency contrast is more seriously affected as V approaches 5%.

References

1. Maccabee, B.S. and Grover, C.G., SPIE Proceedings, Vol. 107, pp. 158, 1977.
2. Goldberg, E., Der Aufbau des photographischen Bildes, Knapp, Halle, 1925.
3. Coleman, H.S., Stray Light in Optical Systems, J.O.S.A., Vol. 37, pp. 53, 1947.
4. Kuwabara, G., On the Flare of Lenses, J.O.S.A., Vol. 43, pp. 53, 1953.
5. MIL-STD-150A, Military Standard Photographic Lenses, Method 35, 1959.

Questions from the Floor

Question 1: Do you measure veiling glare on axis only?

Answer 1: Usually. We also do additional testing throughout the field for ghosts, rings, and local hot spots using a bright source in a dark field.

Question 2: What is the smallest value that can be obtained for a photographic lens?

Answer 2: Low values for veiling glare in consumer quality photographic objectives are about 1 percent.

Question 3: I missed the discussion on surface quality in terms of staining and tarnishing phenomena, which also belongs to cosmetic defects. Do you see any possibility to specify the quality of an optical surface with respect to the above points (before and after coating)?

Answer 3: A quantitative standard is extremely difficult to devise. This characteristic usually falls under "good workmanship" considerations. If the stain does not degrade performance, consideration must be given to what the customer will consider unacceptable from a cosmetic standpoint.

Question 4: Measurements we have made show that often the veiling glare is higher on axis than off axis. The speculation is that multireflections back to the stop or from bevels and mounts tend to be concentrated near the axis.

Answer 4: This is true. The Vivitar measurements are done on axis. Axial measurements might also include ghost images from lens surface reflections. The Japanese Camera Inspection Institute (JCII) has recently developed veiling glare apparatus which measures veiling glare at nine field positions.

Question 5: Having done some prototype work for Vivitar, I can report that scratches and digs are speced on the Vivitar prints as 60-40.

Answer 5: This is the usual level of quality considered acceptable by the consumer market and is consistent with other lenses (Nikon, Canon, etc.).

Question 6: Although you can show that scratches do not affect performance, how do you handle or deal with a customer who complains he will see the scratch?

Answer 6: Our scratch and dig specifications are driven by customer acceptance. Some do comment, but they are a very small percentage.