Optimizing the Light Level

Mike Zecchino

The "optimal" light level provides good fringe contrast without saturation, the best signal-to-noise ratio and an appropriate exposure time for the measurement environment.

Introduction

The optimal light level for any interferometric measurement will depend upon the characteristics of the test part, test system and test environment. To optimize the light level:

- the test and reference beams must have similar intensity
- the interference fringes should have good contrast (i.e., the range from darkest-to-lightest values should make full use of the camera's bit range)
- the intensity level should not "saturate" the camera (i.e., exceeding its upper limit of sensitivity).

Each of these characteristics will be described below. The suggested methods for optimizing the level apply to both temporal phase shifting and vibration-immune Dynamic Interferometry® measurement modes.

Match the Test and Reference Beams

In an interferometer the source beam is divided into two wavefronts. One is directed to a high quality reference and the other to the test optic. The two beams are then reflected back to the interferometer and combined, creating an interference fringe pattern from which the wavefront difference can be determined.

Good light management starts by equalizing the intensity of the test and reference beams to produce sufficient fringe contrast. The test beam intensity will vary depending upon the test part materials and coatings and upon the optical system. A highly reflective sample may return so much light that it overwhelms the reference beam, producing poor fringe contrast. On the other hand, a low-reflecting sample, a system comprised of many optics, or a system which includes a Computer-Generated Hologram (CGH) may return insufficient intensity to match the reference beam.

Some interferometers include a Beam Ratio adjustment which lets you match the intensity of the test beam to the reference beam to maximize contrast. If a system does not include a beam ratio adjustment then another physical change to the system is required. When measuring a highly reflective test part, for example, an attenuating pellicle can be inserted into the test beam to reduce its intensity and increase contrast. In a Fizeau-configuration interferometer an attenuating transmission flat will achieve the same result. For low-reflecting samples or systems, a high-powered laser source in the interferometer may be required to achieve sufficient contrast.

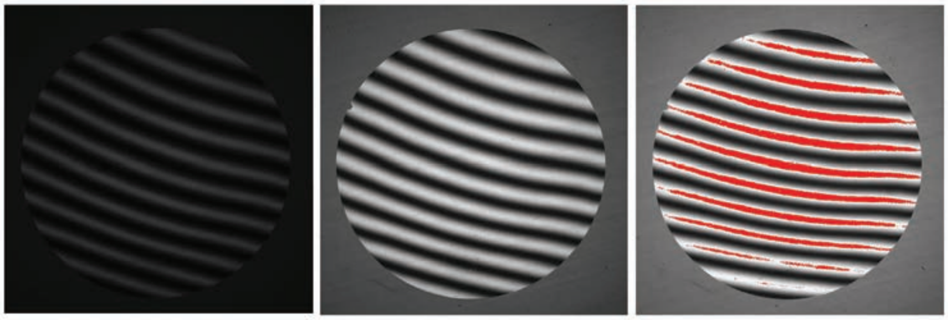

Figure 1. Interference fringes with, a) low intensity, b) good intensity, c) intensity exceeding the camera limit (saturated pixels in red).

Set the Gain and Exposure

The “optimal” light level will produce interference fringes with the best possible contrast; that is, the range from darkest to brightest fringes will span the range of bit values that the camera can sense (i.e., its dynamic range). The lowest intensity values must still be distinguishable from “0.” The highest intensity values must not “saturate” the camera, i.e., exceed its upper bit limit. Saturated values will all be compressed to the highest bit count that the camera can read and report, which will clip the fringe envelope and skew the measurement.

Figure 1b shows good interference fringes, with excellent fringe contrast and no saturation. These light levels will produce excellent measurement results. Figure 1a shows low intensity fringes, with the brightest fringes at roughly 50% of the camera’s maximum bit count. It may be possible to make a measurement at these settings, but data may be lost due to insufficient fringe modulation. In Figure 1c the intensity exceeds the camera’s dynamic range; saturated pixels are shown in red.

The primary settings for optimizing the light level are **Exposure** and **Gain**. In 4D’s 4Sight™ anaysis software these values are adjusted in the **Camera Settings** dialog box.

Exposure (also called “integration time”) is the duration of time that the sensor receives light within one “frame” of the measurement. Increasing the Exposure time enables more light to reach the sensor; however, the longer duration also makes the measurement more susceptible to vibration, turbulence and other noise. these environmental effects will wash out or smear the fringes, just as using a long exposure when taking a photo will blur the picture unless the camera is held very still.

Gain is a multiplier that digitally amplifies the camera’s received light levels. Increasing the Gain raises the intensity of the entire signal. This allows very low—yet valid—intensity values to be discerned and used in subsequent calculations. However, since Gain is a simple multiplier it also raises the camera noise level along with the signal.

A balance must be struck between maximizing the signal-to-noise ratio and reducing the integration time to limit environmental effects. A good rule of thumb is to start with the lowest Gain setting, and increase the Exposure time to just below the saturation point. If sufficient intensity cannot be achieved, then increase the Gain and re-adjust the Exposure.

Figure 2 shows the interference fringes and measured surface of an optic in a high vibration environment. With Exposure = 12.9 ms and Gain = 1 the fringes are sufficiently bright, yet they are being smeared by environmental vibration. The discontinuities in the resulting measured surface are due to phase unwrapping errors caused by the poor quality data. Raising the Gain would allow for a shorter Exposure time which would reduce the impact of the vibration on the measurement.

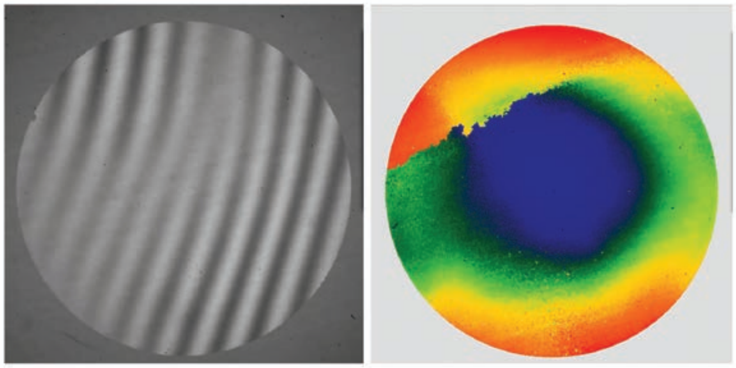

Figure 2. A long Exposure time washes out the fringes (left), leading to unwrapping errors (right). Raise the Gain and lower the Exposure to eliminate this condition.

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Conversely, if the Gain is set too high then noise can be introduced into the measurement. Figure 3 shows a measurement acquired at Exposure = 1.34 ms and Gain = 8. The speckle in the measurement data is noise that has been amplified by the high Gain value. By reducing the Gain to 2 and raising the Exposure to 5 ms the noise is effectively suppressed, and the vibration is also no longer an issue.

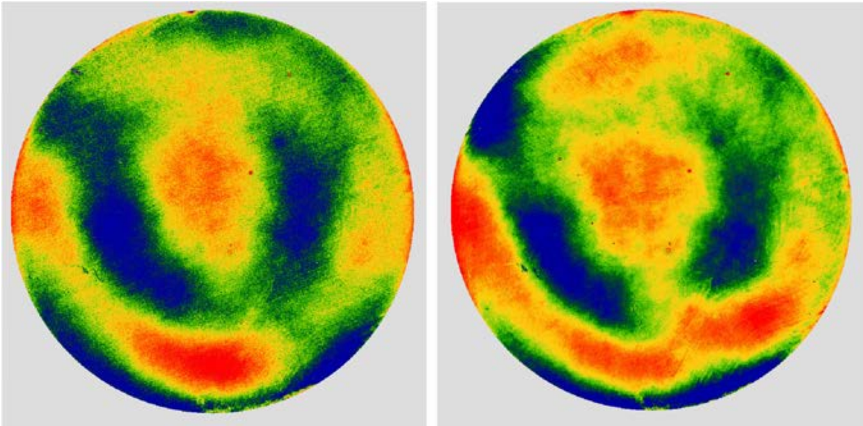

Figure 3. Using Gain 8 results in significant measurement noise (left). Lowering the Gain and increasing the Exposure (right) reduces noise.

You can use the **Modulation Histogram** in the **Signal Thresholds** palette to see the effect of the trade-off between Exposure and Gain. The histogram should have a fairly steep distribution centered as far to the right as possible, as in Figure 4. If you increase the Exposure time and the modulation drops then vibration is likely impacting the measurement. Reduce the Exposure time, and increase the Gain if necessary to improve the modulation histogram.

While maximizing modulation will produce the best possible measurements, you can often achieve perfectly acceptable results even with low modulation values.

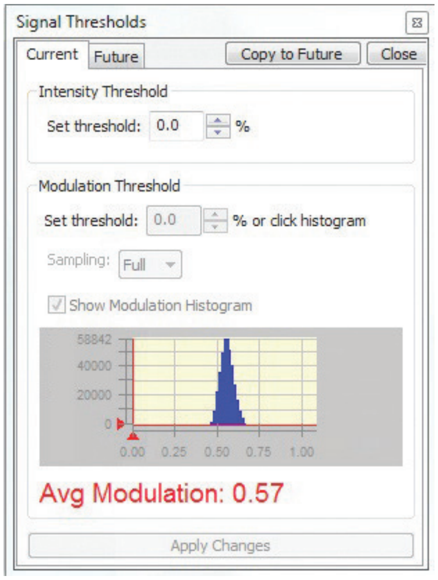

Figure 4. Use the Modulation Histrogram to see the effect of the Gain and Exposure settings.

Using Dynamic Mode to Overcome Extreme Vibration

In traditional Temporal Phase Shifting measurements multiple frames of phase data are acquired serially, with total acquisition time on the order of hundreds of microseconds. In Dynamic Interferometry®, all phase data is acquired simultaneously, enabling measurement with short enough acquisition time to overcome enviromental noise.

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The methods for optimizing the light level discussed above hold true for dynamic measurement as well as temporal measurement. When a very short Exposure time is used, a higher Gain value may also be required, which can introduce measurement noise. If the noise is excessive you can, a) average a larger number of measurements to suppress the noise, or b) extend the Exposure time as much as possible given the current environment.

Bit Depth

Some systems, such as 4D's AccuFiz® Fizeau interferometer, include a third way to adjust the intensity, though only for display purposes. The Bit Depth is the number of bins into which the camera's full dynamic range is divided. a 12-bit camera has 2^{12} bins, or 4096 bits. Calculations for data analysis are always performed at maximum bit depth.

However, consider a case in which Dynamic Mode is being used to overcome extreme vibration. The vibration demands an extremely short Exposure time; yet, even with the Gain set to 8 (maximum) it may be impossible to obtain sufficient light in order to align the system. In this case, changing the **Bits to Show** value on the Camera Settings palette from 12 to 8 will truncate the top (brightest) four bits and promote the remaining eight bits to the eight most significant digits for display. This effectively increases the displayed light level by a factor of 4, making it easier to see and align the optics. It does not, however, affect the final measurement analysis, which is always completed using the full number of camera bits.

Conclusion

Good light management is essential to achieving high quality results from interferometric measurements. Careful attention to the beam balance and Gain and Exposure settings will ensure good measurement results for a wide range of test part reflectivity and environmental conditions.

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