Characterization of speckle reduction with nanosecond-order pulses

Fergal Shevlin

DYOPTYKA, Dublin, Ireland.
`fshevlin@dyoptyka.com`

Abstract. Speckle contrast reduction was investigated for nanosecond-order laser pulses using a phase-randomizing deformable mirror (DM). A 519 nm multimode diode laser with 2 nm linewidth produced pulses from 6 ns to 129 ns. Without DM modulation, contrast C_0 decreased slightly with pulse width, attributed to gradual spectral broadening and multimode dynamics of the laser source. With the DM active at 1.5 MHz, single-pulse speckle contrast decreased monotonically with pulse width τ_p, consistent with averaging over multiple partially independent speckle realizations. Fitted contrasts followed $C_1 = C_0/\sqrt{1 + \tau_p/\tau_D}$ with an effective decorrelation time $\tau_D \approx 12$ ns. The implied DM motion during τ_D corresponded to an angular excursion of approx. 0.03°.

Keywords: Deformable mirror, speckle reduction, laser pulse.

1 Introduction

Our company's phase-randomizing deformable mirror (DM) technology achieves speckle reduction with excellent optical efficiency and at temporal frequencies orders of magnitude higher than alternative techniques such as moving diffusers and shaking fibers. Its effect on far-field intensity distribution is shown in Figure 1 and on speckle patterns in Figure 2.

In an earlier study we proposed a model of DM performance with a *continuous wave* source with narrow spectral linewidth [1]. The observed contrast followed an inverse-square-root scaling to camera exposure periods greater than 20 µs. Herein we explore the complementary regime of a nanosecond-order *pulsed* source with broader spectral linewidth.

2 Experimentation

Sixteen pulse widths between 6 ns and 129 ns were investigated. For every configuration, 256 images were acquired at 10 Hz with camera and laser triggered together such that the exposure period was effectively the pulse width. Neutral density filters with appropriate transmittances were chosen to avoid over- and under-exposure which would have resulted in inaccurate estimation of speckle contrast. This was achieved by looking at the image histogram to ensure that

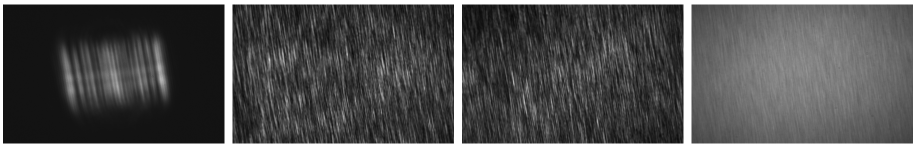

Fig. 1: Far-field intensity distributions of $\lambda_0 = 519\,\text{nm}$, $\Delta\lambda = 2\,\text{nm}$ emission from Thorlabs NPL52C multimode laser diode system configured for 6 ns pulse width. [Left] Single pulse image with DM inactive and effectively planar. [Center pair] Single pulse images with DM active at 1.5 MHz, different surface shapes resulting in different distributions. [Right] Calculated mean of 256 different distributions with DM active.

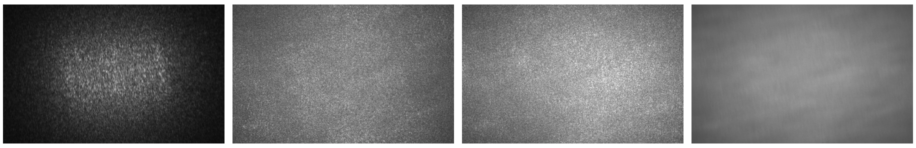

Fig. 2: Far-field speckle patterns arising from the rough surface of a ground glass diffuser located between DM and camera. [Left] Single pulse image with DM inactive and effectively planar. [Center pair] Single pulse images with DM active at 1.5 MHz, different surface shapes resulting in different speckle patterns. [Right] Calculated mean of 256 different patterns has greatly reduced speckle contrast and reveals some diffuser inhomogeneity.

the gamma-like distribution typical of partially-developed speckle did not have its lower and upper tails truncated. Speckle contrasts are plotted and discussed in Figure 3.

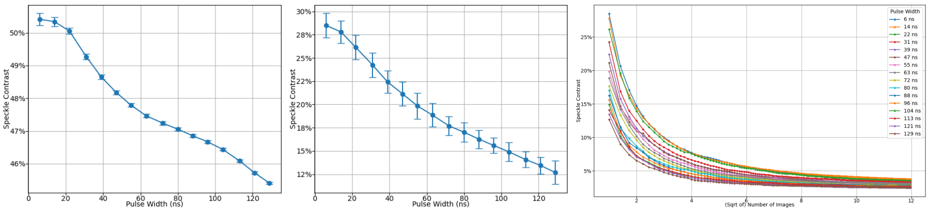

Fig. 3: [Left] Speckle contrast means C_0 and standard deviations for each pulse width with DM inactive. Reduction proportional to pulse width is likely due to broader linewidth and a greater number of longitudinal modes at higher currents. [Center] Speckle contrast means C_1 and standard deviations σ_1 with DM active. The relatively large σ_1 are likely due to variation of angular extent of randomized divergence [2] resulting in greater and smaller diffuser areas contributing to the speckle pattern. [Right] Speckle contrasts of the calculated means of multiple images from each pulse width.

3 Analysis

Figure 4 [Left] shows how a representative curve from Figure 3 [Right] approximately follows inverse-square-root scaling. Letting C_1 and C_N be the speckle

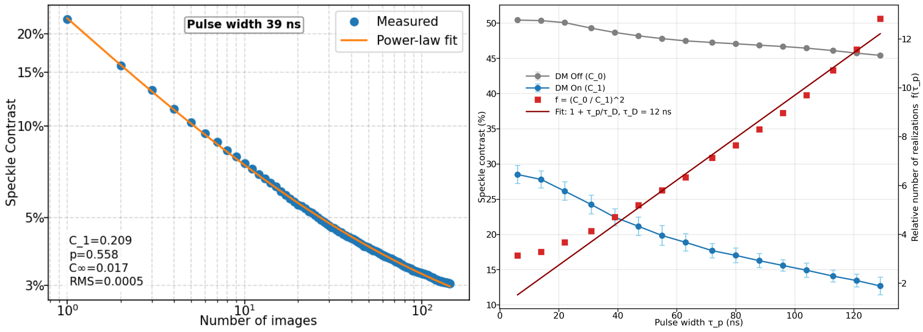

Fig. 4: [Left] Near linear Log-Log plot of speckle contrast of the calculated means of multiple images for one pulse width. [Right] Near linear fit for DM decorrelation time.

contrasts of a single pulse image, and of the mean of N images, respectively, with DM active. A power-law fit $C_N = C_1\, N^{-p} + C_\infty$, yields exponent $p \approx 0.56$ and asymptotic contrast $C_\infty \approx 1.7\%$. The slightly larger exponent compared to the theoretical $p = 0.5$ implies that averaging benefits from both inter-pulse independence and partial intra-pulse decorrelation.

Figure 4 [Right] replots the mean single pulse contrasts from Figure 3 [Left, Center]. For each pulse width, letting C_0 be the observed speckle contrasts with DM inactive. Assuming a power-law fit, $C_1 = C_0\, n^{-1/2}$ or $n = (C_0/C_1)^2$, and further assuming that the ratio of pulse width over DM decorrelation time, $n = 1 + \tau_p/\tau_D$, leads to a near linear least-squares fit for $\tau_D = 12\,\text{ns}$, as shown.

A typical randomized divergence half-angle of 1.5° at DM actuation frequency 1.5 MHz implies a half angle during τ_D of $1.5° \times 1.5\,\text{MHz} \times 12\,\text{ns} = 0.027°$. With the ground glass diffuser positioned 100 mm from the DM, this results in a lateral translation of reflected light of $\tan 0.027° \times 100\,\text{mm} \approx 47$ um which is a physically realistic ground glass correlation distance.

4 Conclusions

We have demonstrated that the speckle contrasts of the means of multiple short laser pulse images follows the same inverse-square-root scaling as is observed with continuous wave laser images. Assuming a similar scaling applies during the short pulses has allowed us to estimate a decorrelation time of 12 ns for our DM operating at 1.5 MHz in an apparatus where speckle is generated by a stationary ground glass diffuser positioned 100 mm from the DM.

References

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