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AN044

Inter-Actuator Stroke Testing of Plate-Type Deformable Mirrors

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1 Introduction

The inter-actuator stroke on a deformable mirror is the maximum safe motion that can be achieved between two adjacent actuators. The inter-actuator stroke of a deformable mirror is a key parameter because it limits the maximum phase slope that can be compensated. For our plate-type deformable mirrors, the inter-actuator stroke is limited by the damage that can occur due to the stress induced in the inter-actuator motion.

In this application note we document a test performed on a 49-actuator (7x7) plate-type deformable mirror (DM). This DM was manufactured with 18-micron stroke actuators placed on a 5-mm square grid. The 2" diameter silicon DM faceplate was coated with a high reflectivity coating.

Figure 1 shows the optical setup we used throughout this testing. We illuminated the DM with a 633nm laser emanating from a single-mode fiber and collimated by a 1m focal length plano-convex lens (Lens 1). The DM retro-reflects the beam along the same path and reflects from a 50% beam-splitting cube to propagate towards the Shack-Hartmann wavefront sensor. In this experiment, the beam is collimated by a 200mm focal length lens (Lens 2) and images the DM onto a Shack-Hartmann wavefront sensor. The AOS Shack-Hartmann wavefront sensor was manufactured by mounting a 6.7mm focal length 150-micron pitch lens array onto an Allied Vision Technologies (AVT) Mako G-419B Gig-E interface camera. This optical configuration allowed more than 60 sub-apertures to be illuminated across the wavefront sensor surface enabling a very high resolution measurement. Imaging was verified by minimizing the intensity variation induced on the beam by poking one actuator of the DM.

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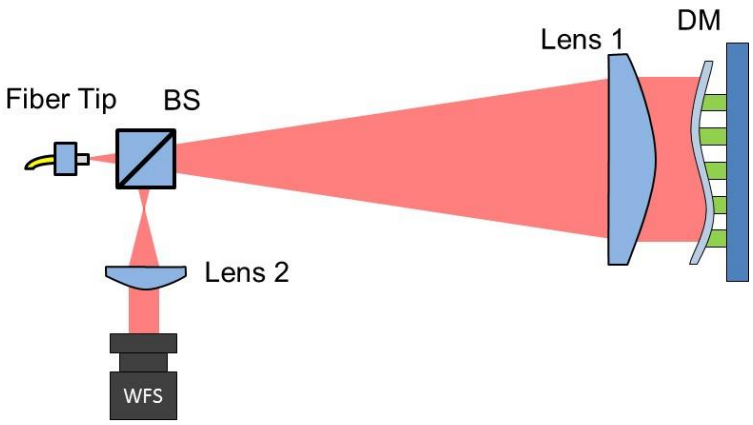

Figure 1: Optical Setup use for DM Evaluation

2 Basic DM Functionality

We began testing this DM by measuring its zero-voltage surface figure (Figure 2), its alignment by poking the center actuators (Figure 3), its influence functions (Figure 4), and its active flattening capability (Figure 5). The faceplate chosen for this build had a significant amount of surface curvature before bonding, so the large focus term in the surface under zero voltage was expected.

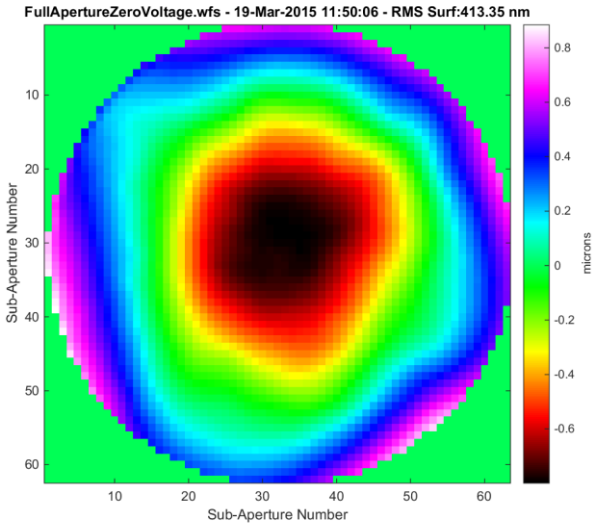

Figure 2: DM Zero-Voltage Surface State

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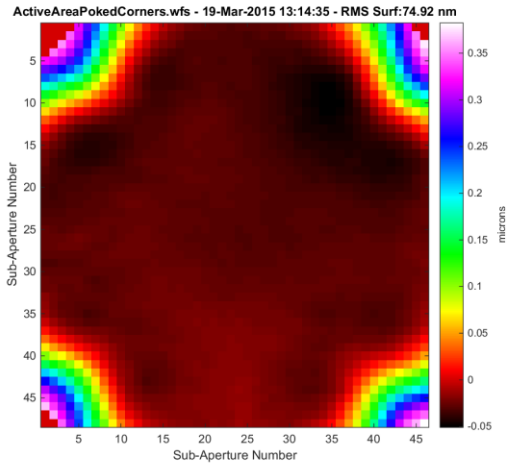

Figure 3: Measurement of the SHWFS Alignment by Poking the Corner Actuators

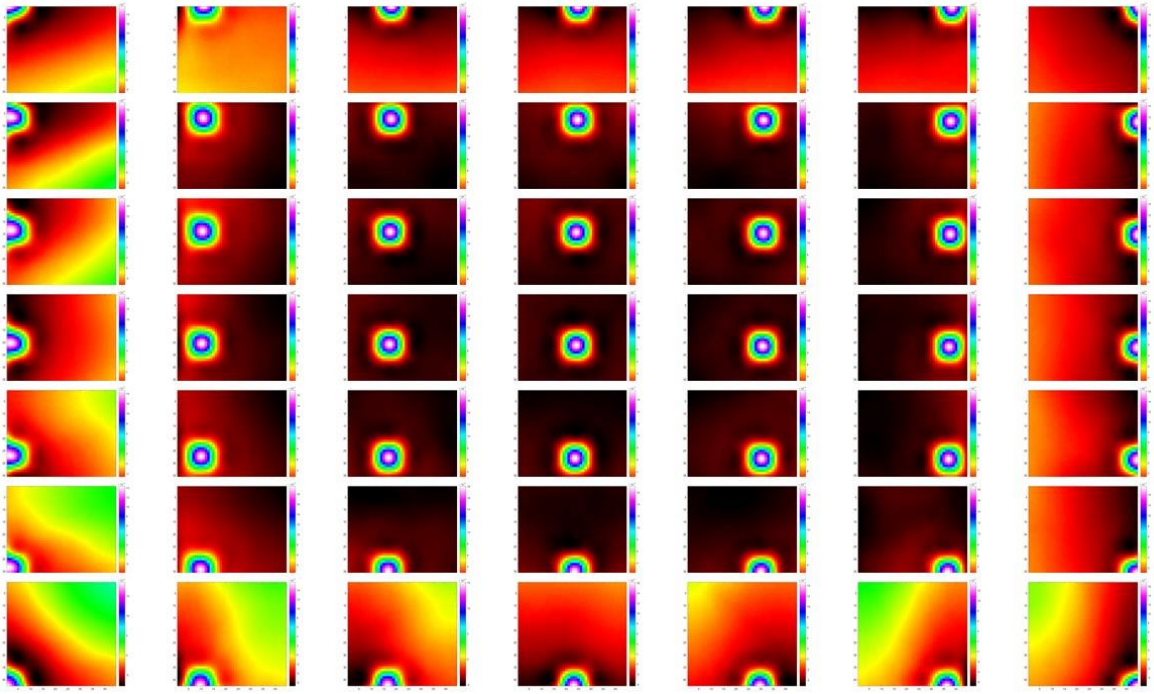

Figure 4: Auto-Scaling False Color Measurement of the Influence Functions

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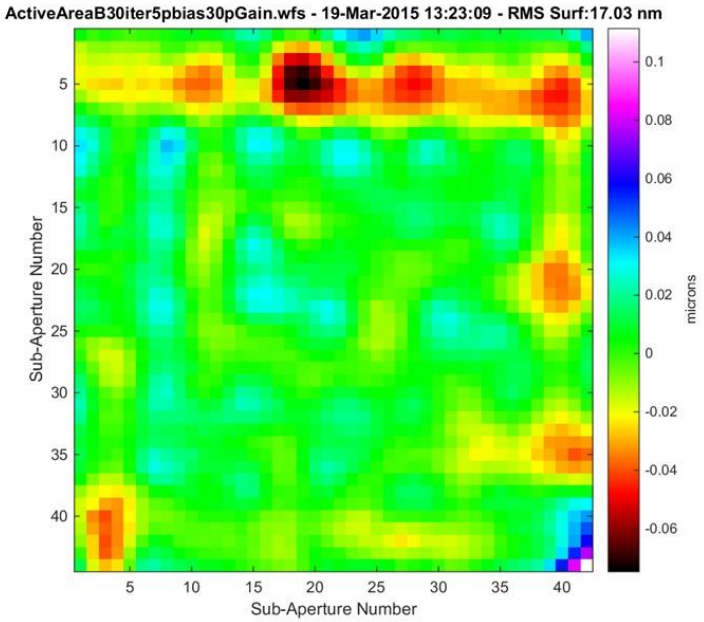

Figure 5: DM Active Flat Surface Measurement

3 Waffle Testing

We first tested the DM capability of withstanding an oscillating waffle pattern. Figure 6 shows a false color plot of the two waffle patterns. The test procedure we applied is as follows:

1. Zero the voltages and measure the surface with a Shack-Hartmann wavefront sensor.
2. Measure the waffle at a given peak-to-valley voltage in each of the two oscillation states on the Shack-Hartmann wavefront sensor. Extend the dynamic range of the WFS if necessary by recentering the AOIs at a lower inter-actuator stroke.
3. Run at least 200 waffle iterations with a ~5ms delay between application of the voltages using the AOS DM Controller software's playback mode. Record the number of oscillations performed.
4. Zero the voltages and measure the surface again.
5. Measure the poke matrix by poking up and down on each actuator and using the difference for the influence function measurement. Bias the DM at 10% and use 5% up and down variations for this measurement.

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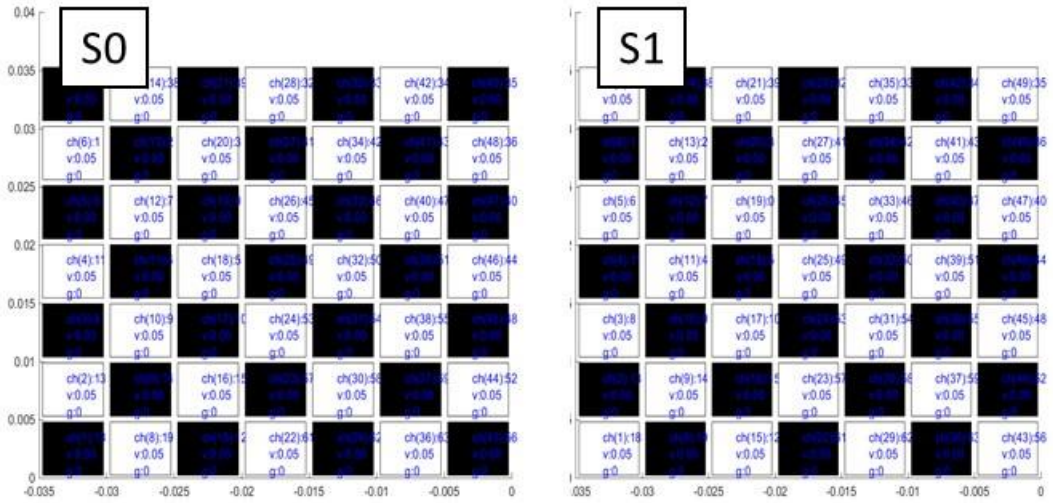

Figure 6: Graphical Representation of the Two Waffle Pattern States

Figure 7 shows an example wavefront sensor measurement of the two waffle patterns.

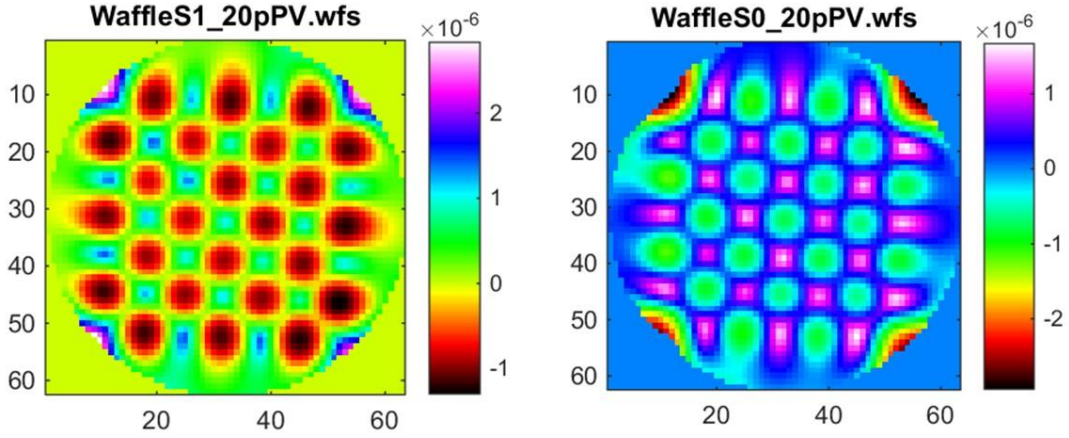

Figure 7: Example Waffle Measurement at 20% PV Voltage

Figure 8 shows the results of peak-to-valley surface deformation measurements made over the central region of the DM during the increasing waffle amplitude testing. The measurement at 40% was actually a duplicate of the 30% measurement, so an additional test was performed afterwards to quantify this data point.

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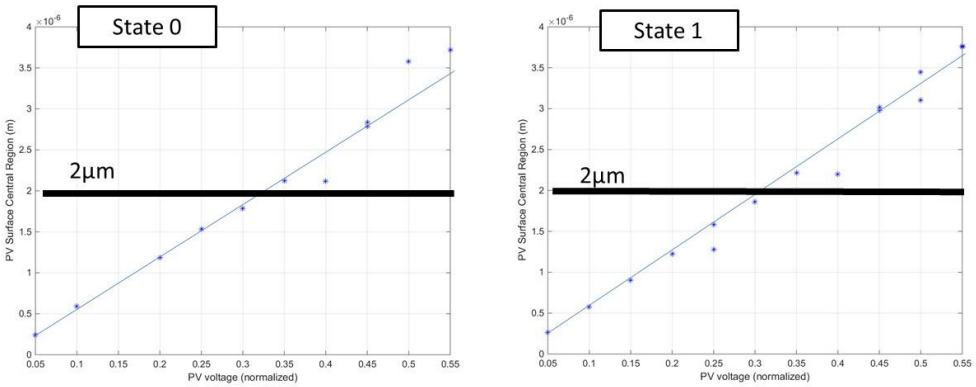

Figure 8: Measured Central Peak-to-Valley Surface Amplitude as a Function of Peak-to-Valley Applied Voltage

Figure 9 shows the measured peak-to-valley surface deformation over the central region of the DM (excluding the edge actuators) for varying peak-to-valley waffle voltages on a normalized scale where 1.0 equals 120V for the two different waffle states. This was measured after two edge actuators had failed, but by excluding these edges we were able to isolate the central peak-to-valley motion of the DM surface. There is a slight difference in the slope of the lines at 9.2 and 7.9 microns for state 0 and state 1 respectively, but the linearity is quite good and the intercept is very small (0.46 and 0.33 microns respectively). On average the slope of the fit is 8.6 microns, which corresponds to the maximum PV inter-actuator stroke for the mirror assuming no damage occurs before that level of inter-actuator stroke is achieved.

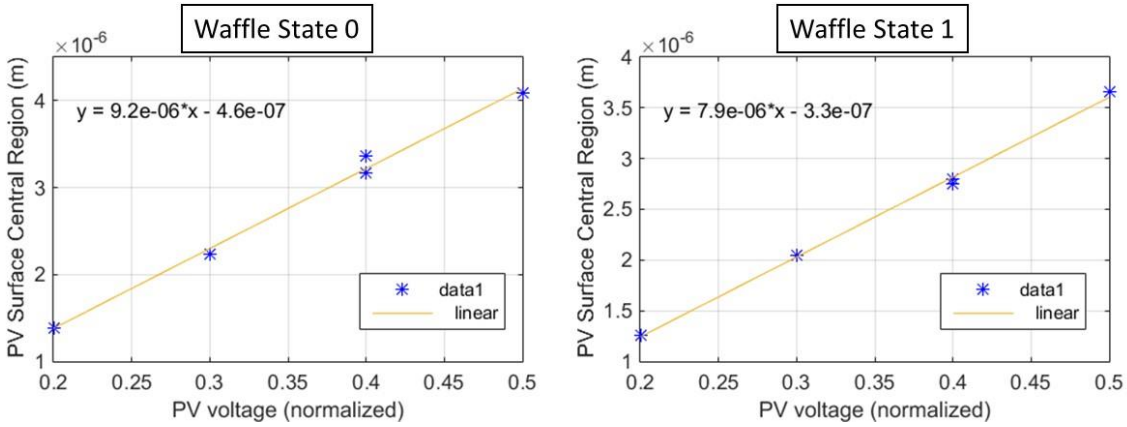

Figure 9: Measured Peak to Valley Surface for Each Waffle State over the Central Region

While following the test procedure outlined, we observed a change in the state 1 waffle shape between the 40% PV amplitude and the 45%. Figure 10 shows how the edge actuator (#42) caused a change in the shape of the waffle pattern due to its failure.

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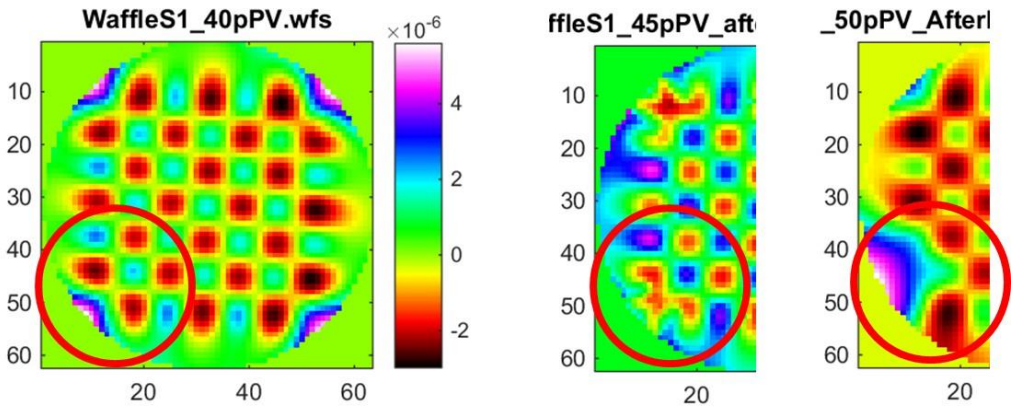

Figure 10: Waffle Pattern Measurement at 40%, 45%, and 50% PV Voltage Amplitude in State 1

Figure 11 shows the RMS wavefront slopes for each influence function after the waffle oscillation tests. Despite clearly observing the change in the waffle pattern after 40% PV due to performance degradation of actuator 42, evidence of this in the poke matrix was not observed until after the 55% PV oscillation. This seems to indicate that damage due to excess inter-actuator stroke can manifest differently for a waffle application than for an influence function measurement.

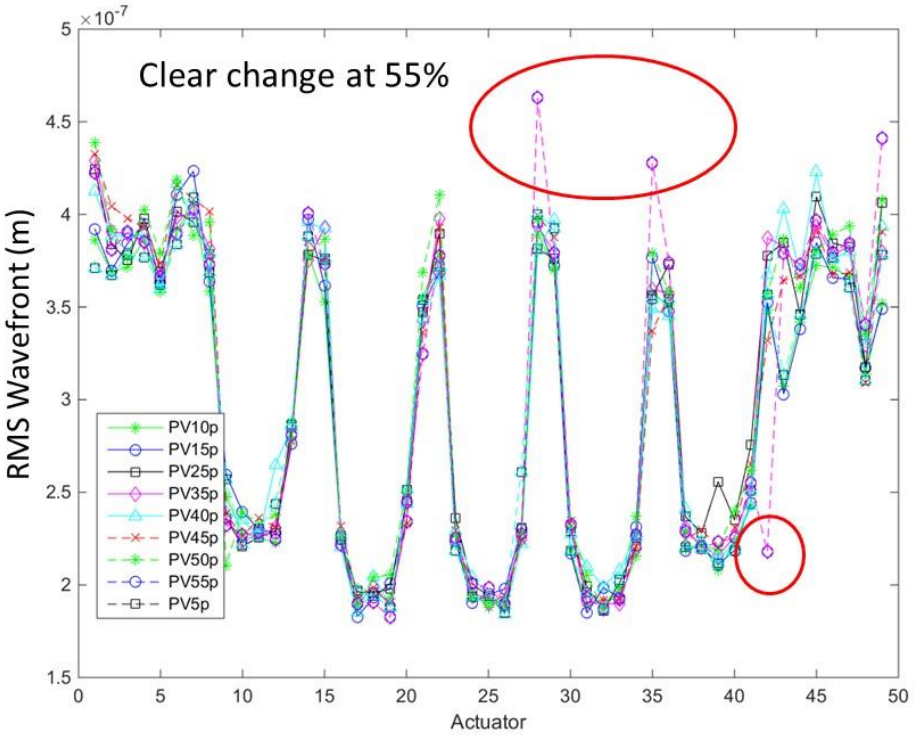

Figure 11: RMS Wavefront Slopes Measured for Each Influence Function after Each Waffle Oscillation Test

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4 Kolmogorov Spectrum Turbulence Testing

After the waffle testing, we tested the DM using a set of Kolmogorov spectrum phase screens. Figure 12 shows the eight different Kolmogorov phase screens evaluated in this test. For this random realization of Kolmogorov turbulence, the maximum inter-actuator stroke was 54% and 36% of the maximum phase amplitude in the vertical and horizontal axes respectively.

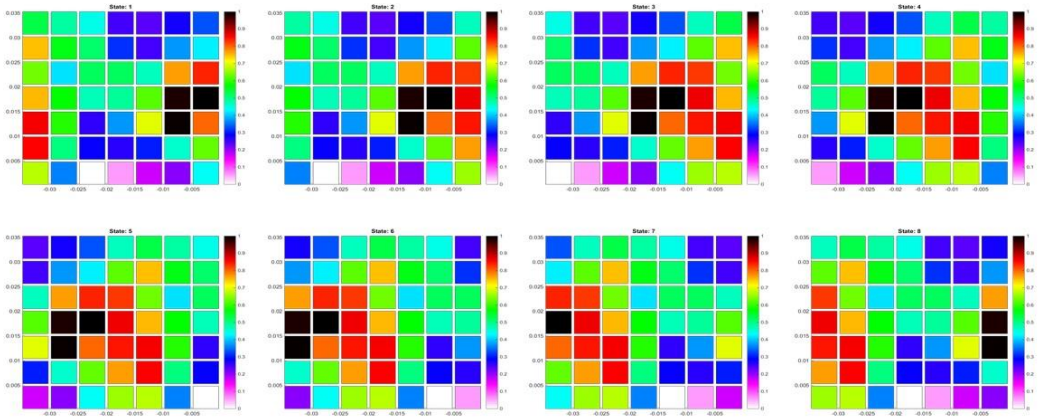

Figure 12: Normalized DM Commands for the Eight States of Kolmogorov Spectrum Turbulence

For this test, we scaled these phase screens to a selected peak-to-valley maximum amplitude and then applied each of these phase screens sequentially at approximately 20 Hz for several seconds. We then measured the influence functions to see if any damage to the DM had occurred. Figure 13 shows the RMS wavefront measured for each influence function after each Kolmogorov sequence. This measurement, made after the waffle testing, was surprising because we did not observe any degradation in the influence function performance. It appeared that the actuator that failed (#42) was exhibiting some form of partial failure that was not as evident in this measurement. Measurements of waffle patterns after this test did show the degraded performance of the edge actuator.

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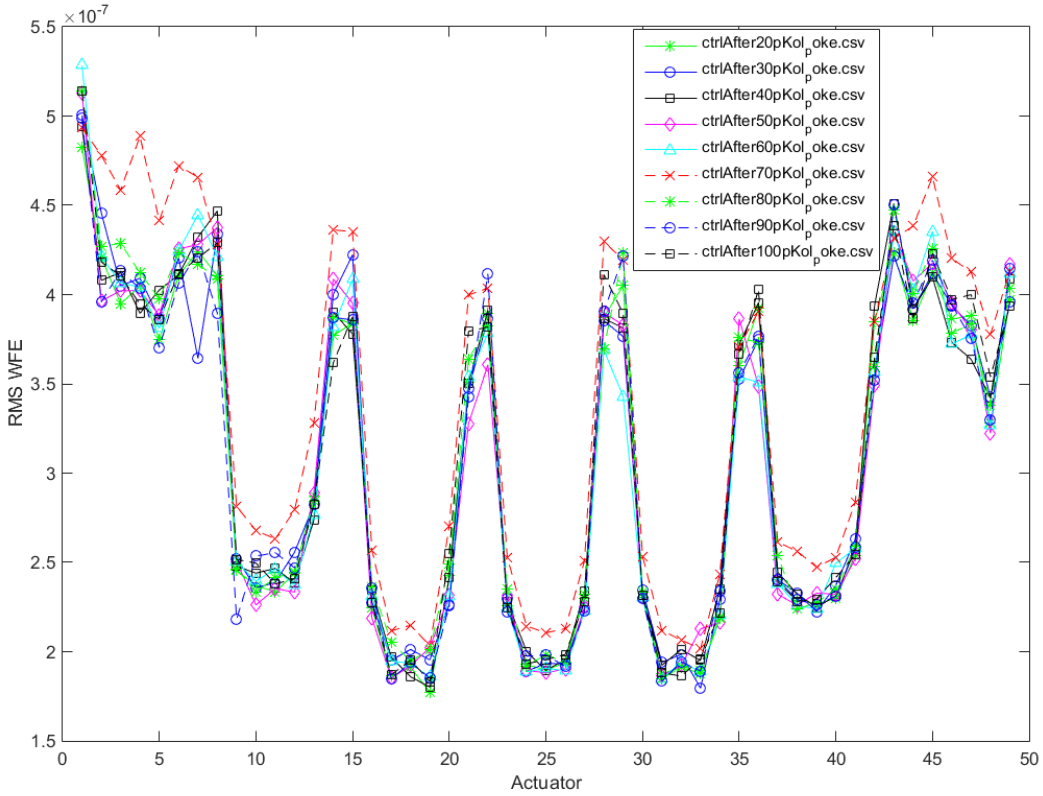

Figure 13: Measurement of RMS WFE Induced by Each Influence Function After Each Kolmogorov Turbulence Sequence

5 Conclusions

During this testing, we observed that there was no damage in the DM up to 40% voltage waffle amplitude, which corresponds to an inter-actuator physical stroke of about 3 microns. This is very similar to the results we have had in prior similar experiments. To provide an engineering margin to account for variations in the manufacturing process and components, we recommend a 1.5 micron inter-actuator stroke.

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6 Appendix: Kolmogorov Spectrum Phase Screen Generation Script

```
%
Setup;

seed0=123;

d = FileInterfaceDM();
%d = AOSDM();
d.LoadDM('PDM2_49x5mm.dm');

nf;
d.ShowDM();
%% analyze SW channel range
Nact = length(d.dm);
for ii=1:Nact;
    sw(ii)=d.dm(ii).ch;
end
sw
sprintf('SW Channel Range: %i to %i\n',min(sw),max(sw))

minSW = min(sw);
for ii=1:Nact;
    d.dm(ii).ch = d.dm(ii).ch - minSW;
    sw2(ii) = d.dm(ii).ch;
    xact(ii) = mean(d.dm(ii).x(2:end));
    yact(ii) = mean(d.dm(ii).y(2:end));
end
xact = xact-min(xact);
yact = yact-min(yact);
nf; bar(sw2(sw2>=32),ones(1,length(sw2(sw2>=32))));
hold on;
bar(sw2(sw2<32),ones(1,length(sw2(sw2<32))),'r');

nf; d.ShowDM();
% d.SaveDM('PDM2_49x5mm_First64Channels.dm');

%% establish turbulence patterns - NOT taking into account varying actuator
stroke

k = kolmogorovTurbulenceScreen();
k.seed = seed0;
nxy = 8; dxy = 5e-3;%/8;
k.nxyFull = nxy;
k.nxySection = nxy;
k.dxy = dxy;
k.GenerateKTS();
k.SelectSection();
phs = k.ScreenSection;
xv = ((1:nxy)-1)*dxy;
yv = ((1:nxy)-1)*dxy;
[xx,yy]=meshgrid(xv,yv);
nf; show(xv,yv,phs);
hold on;
plot(xact,yact,'r*');
```


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```
for ii=1:Nact;
    x(ii) = mean(d.dm(ii).x(2:end));
    y(ii) = mean(d.dm(ii).y(2:end));
end;
nf; plot(x,y,'b*');

% make DM resolution phase screens
phs0 = phs - min(phs(:));
phs0 = phs0 ./ max(phs0(:))
dact = 5e-3;
for ii=1:nxy;
    phs = phs0([ii:nxy 1:(ii-1)],:);
    dpdx = diff(phs);
    dpdy = diff(phs')';
    for jj=1:length(d.dm)
        xi = round( xact(jj) ./ dact)+1;
        yi = round( yact(jj) ./ dact)+1;
        z{ii}(jj) = phs(xi,yi);
    end;

    clf;
    subplot(2,2,1); show(phs ); title(sprintf('phase - %i',ii));
    subplot(2,2,3); show(dpdx); title('dpdx'); caxis([-1 1]);
    subplot(2,2,4); show(dpdy); title('dpdy'); caxis([-1 1]);

    dpmaxx(ii) = max(max(abs(dpdx)));
    dpmaxy(ii) = max(max(abs(dpdy)));

    drawnow; pause(1.5);
end;

nf; plot(dpmaxx,'b*-'); hold on; plot(dpmaxy,'r-');
legend('X','Y','Location','Best');

% create dm patterns
d2 = d;
dVvec = 0.1:0.1:1.0;
nf;
for dV = dVvec;
    for state=1:length(z);
        for jj=1:length(xact)
            d2.dm(jj).v = z{state}(jj).*dV;
        end;
        clf;
        d2.ShowDM();
        caxis([0 1]); colormap(hsvJM256);
        colorbar; axis image;
        drawnow;


d2.SaveDM(sprintf('PDM2_49x5mm_kol_Amp%i_S%i.dm',round(dV*100),state));
    end;
end;
```


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