ACTIVE OPTICAL SYSTEMS

AN026

Power Requirements for a Deformable Mirror in Kolmogorov Spectrum Turbulence

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Abstract

When considering the potential for adaptive optics in a system, the power consumption is often a key consideration. The conservative estimates that are typically made are often substantially over estimate the required drive power. In this application note, we analyze the power required for a deformable mirror and drive electronics to compensate Kolmogorov spectrum turbulence.

Capacitive Actuator Power Requirements

We were interested in determining the power required to drive a deformable mirror that is compensating for Kolmogorov-spectrum turbulence. We began by determining the power required to change a voltage on a deformable mirror actuator. We used a fairly simple model to calculate the electrical power requirements. PZT actuators are electrically capacitors. Our standard throw actuators have about 0.25 µF of capacitance and our long throw actuators have about 0.5 µF. The energy required to charge a capacitor is CV^2. Power is energy over time. For 120 V operations at 0.25 µF capacitance, the energy to charge the capacitor is 3.6 mJ. At 1,000 times per second, we require a current of 3.6 W.

Analysis of Kolmogorov Spectrum Turbulence

We then looked at determining the required voltage change on an actuator at a given time step by assuming frozen flow and a Kolmogorov spectrum turbulence screen. For this analysis we assumed ideal control in which the actuators were driven to their optimal position immediately without the effects of an integrator control system or latency since this is the worst case electrically. The phase structure function of the atmosphere, given by

$$D_\phi = 6.88\left(\frac{r}{r_0}\right)^{5/3}$$

tells us about the average phase difference between any two points separated by a distance. We wanted to know what phase difference would capture more like 90% of the phase differences, not

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just 50%, so we performed some analysis on computer-generated Kolmogorov spectrum phase screens using the Fourier transform generation from the atmospheric PSD. From these screens we were able to calculate the actual phase difference at different radii and then do statistics on the results to determine the phase difference that captured 90% of the phase differences at given radii. Figure 0.1 shows the phase difference captured at varying percentages with respect to radius and the theory result which represents 50%. The 50% lines are very close in this result, but not perfect due to the limited statistical sample size.

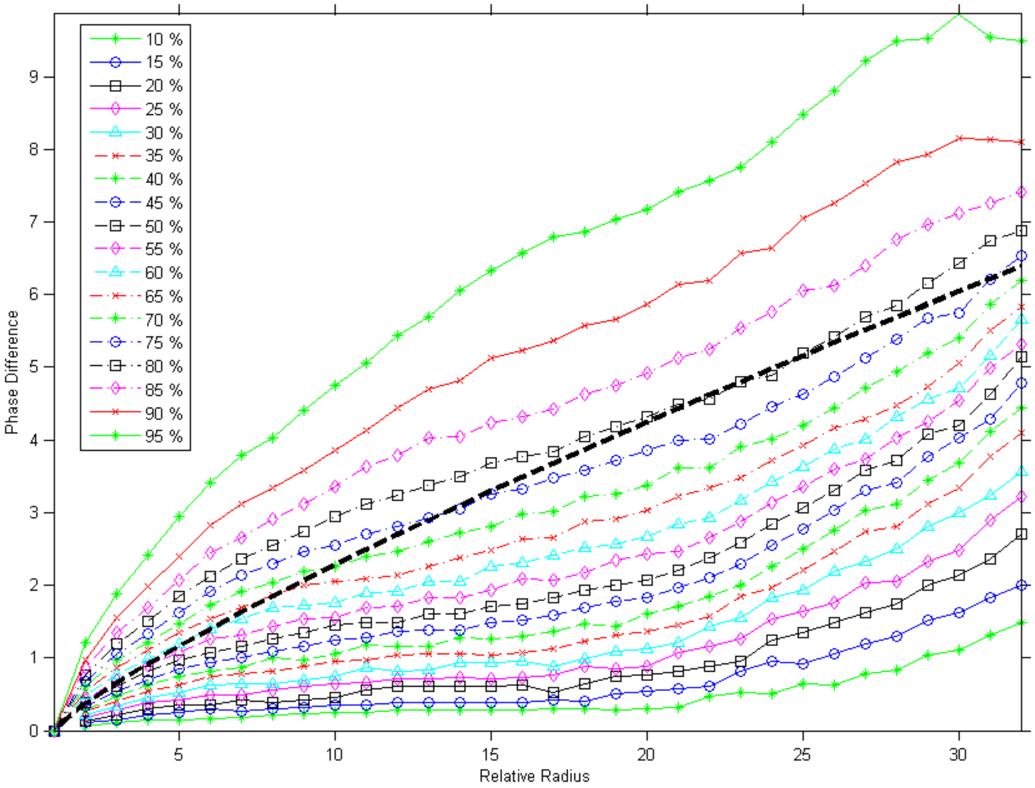

Figure 0.1 – Phase difference at different capture percentages relative to the distance between the points in relative numbers

We then were able to modify the 50% result of the phase structure function to include a capture percentage coefficient by modifying the phase structure formula as follows,

$$D_\phi = C(p)\left(\frac{r}{r_0}\right)^{\frac{5}{3}},$$

where C(p) is the modified coefficient for the capture percentage p. Figure 0.2 shows the capture coefficient with respect to capture percentage and a fit to the simple curve,

$$C(p) = 14p^{2.1}.$$

This figure also shows that the 50% point from theory corresponds well to our 50% results.

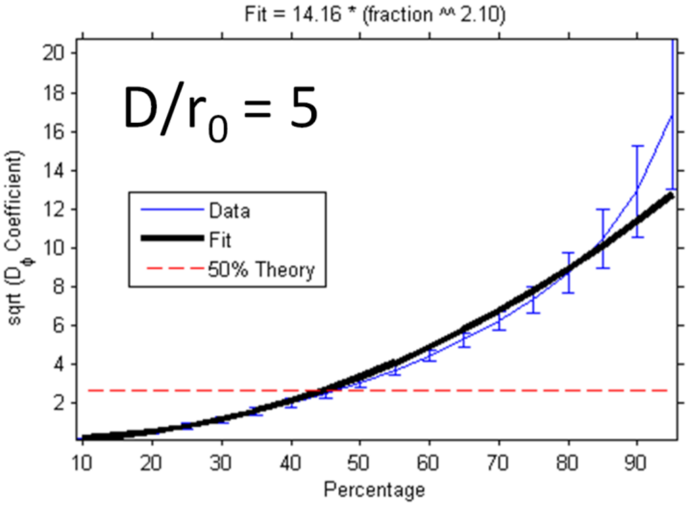

Figure 0.2 - The capture percentage and the fit to the basic curve

Application to DM/DE Power Requirements

Based on this, if we wanted to capture 90% of the cases, we can determine the phase difference for different actuator spacing and different wind velocities (again assuming frozen flow). We did an example case in a spreadsheet that we present below as Table 0-1. This analysis was compared to the maximum power possible in which an actuator was slewed over its whole range every time step. We found that for the case of turbulence that we chose, even the 90% capture case showed nearly a 1000x reduction in the power requirements over full-range slew.

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Table 0-1 – Results of Power Requirements Analysis

Parameter	Value	Value	Value	Value	Value	Units
Capture Fraction	0.5	0.6	0.7	0.8	0.9	
Coefficient	3.26561547	4.789009	6.619633	8.762278	11.22115	
separation	5.00E-03	5.00E-03	5.00E-03	5.00E-03	5.00E-03	m
D_phi	0.229754181	0.494111	0.944063	1.654121	2.712739	radians^2
Delta Phase	0.4793268	0.70293	0.971629	1.286126	1.647039	radians
	7.63E-08	1.12E-07	1.55E-07	2.05E-07	2.62E-07	m
Actuator Motion	3.81E-08	5.59E-08	7.73E-08	1.02E-07	1.31E-07	m
Transient Time	9.54E-06	1.40E-05	1.93E-05	2.56E-05	3.28E-05	s
Voltage Change	1.14E+00	1.68E+00	2.32E+00	3.07E+00	3.93E+00	V
Charging Energy	3.27E-07	7.04E-07	1.35E-06	2.36E-06	3.87E-06	J
Peak Power	0.0343	0.0503	0.0696	0.0921	0.1180	W
Average Power	0.0003	0.0007	0.0013	0.0024	0.0039	W
Peak to Average Ratio	104.8668	71.5085	51.7332	39.0828	30.5187	
Max Power	3.6000	3.6000	3.6000	3.6000	3.6000	W
Max to Average Ratio	10997.0522	5113.4623	2676.3231	1527.4688	931.3904	

Conclusions

In conclusion, we analyzed the power required for a typical case of Kolmogorov spectrum turbulence and found that the power was nearly 1000 times lower than the maximum power case. This has profound implications for size and weight as well in future systems.