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AN055

Scaling of Inter-Actuator Stroke with Faceplate Thickness and Inter-Actuator Distance

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1 Introduction

In AN044, we established a recommended 1.5um inter-actuator (IA) stroke using a 5-mm pitch and 18-um stroke actuators with 3x3mm cross section and a 0.75mm thick faceplate. In this application note, we seek to scale these results with faceplate thickness and inter-actuator spacing.

2 Analytical Approach

Timoshenko's Theory of Plates and Shells shows that the maximum deflection of a simply supported rectangular plate is given by,

$$w_{\max} = \frac{Pa^2}{2\pi^3 D}\sum_{m=1}^{\infty}\frac{1}{m^3}\left(\tanh\,\alpha_m - \frac{\alpha_m}{\cosh^2\alpha_m}\right) = \alpha\frac{Pa^2}{D} \qquad (147)$$

where P is the force, a is the side length (which is 2x the actuator spacing for our analysis), α is 0.0116 for a square plate, and D is

$$\frac{Eh^3}{12(1-\nu^2)} = D \qquad (3)$$

where E is the modulus, h is the plate thickness, and v is Poisson's ratio. Although not as perfectly relevant to our case of an array of actuators, Timoshenko also gives a relationship for tensile stress in a circular plate with clamped edges loaded at the center as,

$$\sigma_{\max} = \frac{P}{h^2}(1+\nu)\left(0.485\log\frac{a}{h} + 0.52\right) \qquad (97)$$

where a is the circular plate radius (equal to the actuator spacing here). The stress is essentially proportional to the force P over the plate thickness squared.

The deflection equation gives us the effective Hooke's law spring constant that can be simplified to,

$$F = kx = \left(\frac{D}{\alpha a^2}\right)w_{max} \rightarrow k \cong 7.18\frac{Eh^3}{(1-\nu^2)a^2}$$

If we neglect the constants and material parameters E and v, $k \propto h^3/a^2$.

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Neglecting scaling factors and material parameters, the ratio of max displacement to max stress is given by,

$$\frac{\sigma}{w} = \frac{P}{h^2} * \frac{D}{Pa^2} = \frac{Eh^3}{12a^2h^2(1-v^2)} \propto \frac{h}{a^2}$$

where h is the plate thickness and a is double the actuator spacing. This is the scaling relationship for the inter-actuator stroke.

We can safely assume that there is a pull force on the actuator that will cause damage to the actuator. If we use the empirically derived 1.5um maximum IA stroke with a 0.75mm plate thickness and 5mm spacing, we can use this equation to scale these results to different actuator spacing and plate thicknesses. Table 1 shows the results of using this analytical relationship for different actuator spacing and plate thicknesses. This table does not take into account some of the realities of different actuator architectures, actuator lateral dimensions, actuator layout boundary conditions, and challenges associated with manufacturing, but is a good guide.

Table 1: Analytical Scaling of the Empirical Inter-Actuator Spacing Results

		Thickness (mm)			
Spacing (mm)		**0.75**	**0.5**	**0.25**	**0.1**
	2.5	0.4	0.6	1.1	2.8
	3	0.5	0.8	1.6	4.1
	4	1.0	1.4	2.9	7.2
	5	1.5	2.3	4.5	11.3
	6	2.2	3.2	6.5	16.2
	7	2.9	4.4	8.8	22.1

3 Finite Element Analysis Results

3.1 Empirical Result Analysis

We'll begin by using the FEA to analyze the 49 actuator DM that we tested in the IA destructive testing. Pushing on central actuator with 1N of force produced the following results. The mirror displacement is 0.1162 microns producing a 1.35 MPa maximum stress. Figure 1 illustrates the FEA results.

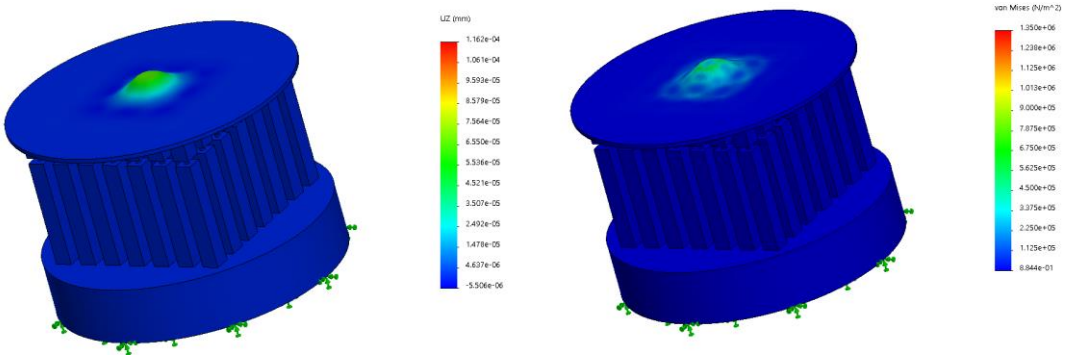

Figure 1: (left) Displacement and (right) Stress for a 1N force on the 49-Actuator DM

Using iso-clipping on the stress plot (Figure 2), we were able to determine that the stress in the actuator at this system is 110kPa. If we scale the amplitude linearly by 25.8 to make the

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displacement 3 microns, the maximum stress increases to 35MPa and the actuator stress increases to 2.8MPa. The blocking pressure for this actuator is 34 MPa. The manufacturer recommends a maximum reverse voltage of 10%. This would correspond to a reverse pressure of 3.4 MPa, which is very close to the maximum actuator stress thereby confirming the results.

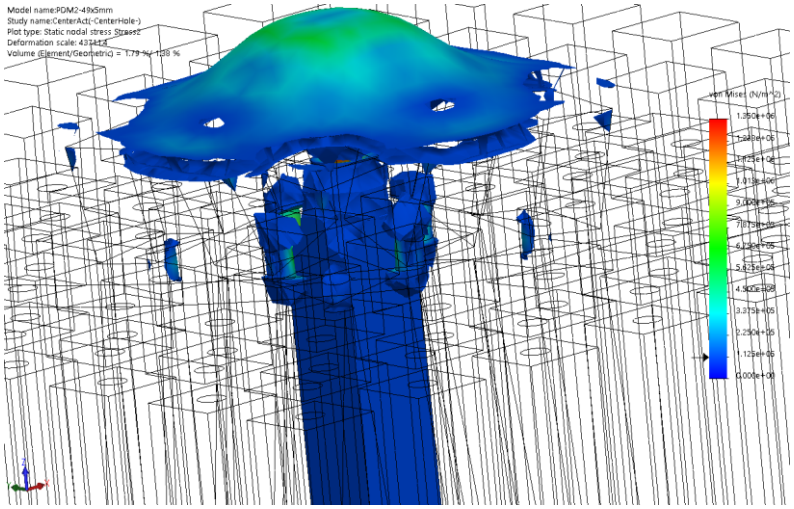

Figure 2: Iso-Clipping Rendering of the Stress at 110kPa

3.2 Varying Faceplate Thickness FEA Study

We performed finite element analysis on the 49-actuator DM model with 5mm spacing using the 750 and 500 micron thick faceplates. This time we use a 1mm minimum curvature-based mesh. The stress for the 1N force inside the actuators was approximately the same for each simulation, but the z-axis (normal the faceplate) displacement was 1.475 times more for the .5mm faceplate relative to the .75mm one and 3.325 times more for the 0.25mm faceplate relative to the .75mm one. This is approximately linear with the change in faceplate thickness as is predicted by the analytical equations above.

Parameter	0.75mm Thickness	0.5mm Thickness	0.25mm Thickness
Maximum Stress	1.6MPa	1.6MPa	2.8MPa
Actuator Maximum Stress	111kPa	111kPa	111kPa
Z Displacement	120nm	177nm	399nm

4 Conclusions

In this application note, we have developed a scaling relationship for inter-actuator stroke that takes into account the two key engineering parameters: faceplate thickness and inter-actuator stroke. The IA stroke increases linearly with faceplate thickness and as the inverse square of the actuator spacing. We confirmed the results with respect to faceplate thickness using finite element analysis.

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