Electro-Thermal Dynamics in MEMS with V-Beam Actuators

MEMS

MEMS devices are classified into electrostatic, electromagnetic, piezoelectric, and electro-thermal types based on their actuation source. Electro-thermal actuation, leveraging thermal expansion from joule heating via current through actuator beams, is utilized in applications like tunable capacitors, optical modulators, RF switches, and micro-manipulators. These actuators offer compactness, stability, and high force at low voltages.

***Figure 1** - Electrothermal actuator [1].*

CAD Model

A combined magnetostatic and thermo-structural analysis evaluates the V-beam electro-thermal actuator. This actuator comprises a 30×6mm shuttle linked to six beams (26.4mm in length and 1mm in width) and anchored by two 6×30mm supports, with an overall thickness of 1mm along the Z axis.

***Figure 2** - a) Drawing of the V-beam thermal actuator b) 3D Model of the thermal actuator.*

Simulation Setup

Using EMS's Magnetostatic module, combined with steady-state thermal and structural analyses, enables the calculation and visualization of the shuttle's temperature and displacement. The process entails: selecting materials, defining electromagnetic and thermal inputs, setting structural boundaries, meshing, and initiating the solver.

Materials

For our case study, we utilize specific material properties as detailed in Table 1:

***Table 1** - Material properties.*

Part	Density *(Kg/)*	Relative permeability	Electrical conductivity *(S/m)*	Specific heat capacity *(J/kg. K)*	Thermal conductivity *(W/m. K)*	Elastic Modulus *(Pa)*	Poisson's ratio	Thermal expansion coefficient (1/K)
Aluminum	2700	1	3.57 E+07	910	235	71 E+09	0.36	23.1 E-06
air	0	1	0	1000	0.024	Not required		

Electromagnetic Inputs

The thermal actuator is described as a solid coil that conducts a 40 A DC current.

Figure 3 *- Applied current input.*

Thermal Input

The thermal convection settings for the ambient air in the simulation specify an initial (ambient) temperature of 303.15 K and a convection coefficient of 15 W/m²K for the surrounding air.

Mechanical boundary conditions

Fixed boundary conditions are applied to the thermal actuator's anchors, as illustrated in Figure 4.

Figure 4 *- Applied mechanical boundary conditions.*

Meshing

Mesh Control is implemented on the shuttle and the six beams, targeting areas of anticipated maximum temperature and displacement, as depicted in Figure 5.

Figure 5 *- Mesh of the model.*

Results

EMS enables the visualization of results through 3D plots and curves, showcasing parameters such as applied current density, temperature and heat flux distribution, mechanical displacement, stress, and more.

Table 2 presents the DC resistance of the V-beam thermal actuator as determined by EMS simulations alongside an analytical comparison, highlighting the resistance of the thermal actuator against the analytical value for comprehensive analysis.

	EMS	**Analytical (reference)**
Electric Resistance ()	5.59 E-04	5.73 E-04

[1]

[1]

[1]

I=40 A (current intensity)

Ra =4.96E-04 (Ambient temperature resistance)

Ac =1553.6 m (convection area)

hc=15 W/.K(convective heat transfer coefficient)

k=3.9.10-3 1/°C (temperature coefficient)

Figure 6 *- Plot of the applied current density.*

Figure 6 illustrates the distribution of current density within the V-beam thermal actuator, showcasing how the current flows through the device.

Figure 7 *- Plot of temperature distribution.*

Figure 7 depicts the temperature distribution within the V-beam thermal actuator, showing a peak temperature of 63.8 °C.

Figure 8 *- plot of Y displacement plot .*

Figure 8 displays the displacement distribution along the Y axis in the V-beam thermal actuator, reaching a maximum displacement of 0.163 mm. This maximum temperature of 63.8 °C occurs on the beams, attributed to the concentration of current in that area. The shuttle shows the highest mechanical deflection, 0.163 mm, along the Y axis due to this effect. Table 3 compares the temperature and displacement results obtained from EMS simulations with reference values, showcasing the accuracy of EMS in predicting thermal and mechanical behaviors.

Table 3: *Comparative table between EMS and the reference [1].*

	EMS	**Reference [1]**
Temperature (°C)	63.8	63.5
Displacement (mm)	0.163	0.165

Conclusion

In conclusion, this application note delves into the electro-thermal modeling of MEMS devices, particularly focusing on the V-beam thermal actuator. MEMS devices, categorized into various types based on actuation sources, find applications in fields like tunable capacitors, optical modulators, RF switches, and micro-manipulators. The study utilizes electro-thermal simulations to evaluate the thermal and mechanical behavior of the V-beam actuator. By combining magnetostatic and thermo-structural analyses, the study accurately predicts parameters such as temperature distribution, displacement, and electric resistance. Results showcase the effectiveness of the electro-thermal simulations in capturing the intricate behaviors of the actuator, with temperature peaking at 63.8°C and maximum displacement reaching 0.163 mm along the Y-axis. Comparative analysis with reference data confirms the reliability and accuracy of the simulations. Overall, this study contributes to the understanding of electro-thermal dynamics in MEMS devices, emphasizing the potential for precise control and efficient design of such devices in various applications.

References

[1]. Radu-Stefan Chiorean, "Electro-Thermo-Mechanical Modeling of V-beam Actuator",8th international conference interdisciplinarity in engineering INTER-ENG 2014,9-10 october 2014, Tirgu-Mures, Romania.