Characterization, Analysis and Modeling of a MEMS Based Nitinolactuator

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Abstract—The paper presents the modeling and simulation of a Nitinol based microactuator for evaluation of the characteristics of this microactuator. The displacement, pressure, stress and von mises stress characteristics are presented and verified using COMSOL Multiphysics 4.4. The characterization of these parameters proves to be useful in the development of the design of these smart actuators exhibiting shape memory effect. The resistivity of Nitinol is suitable for Joules Heating. Therefore microactuator in this current study is of dimensions 1000×600×200µm is characterized at different temperature during the martensitic and austenitic phase transformation.

Index Terms—microactuator, shape memory effect, phase transformation, nitinol, austenitic, martensitic

I. INTRODUCTION

Smart actuators are the need of current times due to high compatibility, robustness, large force and cost effectiveness [1]. These actuators also possess a high work output per unit volume and is used in many actuation applications. Nitinol is a prospective material for various microactuating mechanisms. These actuators find major application in microdevices including the long range of micromanipulators viz. micropumps and valves [2].

The specifications of the Nitinol based microactuator are,

Range of motion=5% of the length
Force generated=600MPa(approximately)
Response speed=100Hz
Driving Voltage=0.5-10volts
Work output per volume=3x10^7 J/m^3

Modeling and analysis of these actuators provide an useful information for designing and developing of these actuating components in MEMS (Micro Electro Mechanical Systems) technology.

II. DISPLACEMENT CHARACTERISTICS

The expansion takes place in the actuator at higher temperature as the phase transformation takes place from the martensitic phase to the austenitic phase. The growth in the actuator is given as [3].

$$\varepsilon = 1 - \exp[a^M(M_s - T) + b^M \sigma]$$

(1)

$$\varepsilon = \exp[a^A(A_s - T) + b^A \sigma]$$

(2)

a^M and b^M are stress coefficients during martensitic phase,
M_s =Phase change temperature
T=temperature at which the phase transformation occurs
\sigma=equivalent stress.

In the austenite stage the growth is given as,

$$\varepsilon = \exp[a^A(A_s - T) + b^A \sigma]$$

(2)

a^A and b^A are the stress coefficients in the austenitic phase
A_s is the phase change temperature in the antiphase.

The displacement analysis are shown in Fig. 1.

Figure 1. The displacement in the microactuator at 400K (FEM analysis)

The elongation in the microactuator increases with an increase in the temperature. In the austenitic phase greater elongations takes place.

The displacement characteristics are demonstrated in Fig. 2.
The Pressure in the actuator during the phase transformation is given as,

\[ P = F [a(1 - e^2) - b] \]  

where 
\[ F = \text{force in the actuator}, \]
\[ a = \frac{3}{\tan \frac{\alpha}{2}} \]
\[ \alpha = \text{angle formed during the phase transformation}, \]
\[ e = \text{strain in the actuator}, \]
\[ b = \frac{1}{\sin \frac{\pi}{2}} \]

The pressure in the actuator is temperature dependent and increases with an increase in the temperature. The analysis depict the increase in the pressure along with the phase transformation. The simulation results using COMSOL Multiphysics 4.4 for the pressure across the actuator are demonstrated in the Fig. 3.

The Shape Memory behavior of stress in the actuator can be described using the Clausius-Clapeyron relationship [4].

\[ \frac{d\sigma}{dT} = -\frac{\rho \Delta H}{\Delta \varepsilon T} \]

\( T = \text{Transformation temperature}, \)
\( \Delta H = \text{Latent heat}, \)
\( \rho = \text{density of Nitinol} \)
\( \Delta \varepsilon = \text{strain due to phase transformation} \)

The stress analysis are shown in Fig. 4.

Stress Tensor analysis (X-component) are exhibited in Fig. 5.

Stress Tensor analysis (Y-component) in Fig. 6.

Stress Tensor (Z-component) is shown in Fig. 7.
V. STRAIN ANALYSIS

The strain model during the Joules Heating can be given as [5],

$$\varepsilon = \alpha_e (T - T_0)$$

$\varepsilon$=strain in the actuator,
$\alpha_e$=coefficient of thermal expansion,
$T$=Phase Transformation temperature,
$T_0$=Ambient temperature. The strain analysis prove to be useful in the design of actuator for various micromanipulation application [6]. The strain analysis are demonstrated in Fig. 8.

The strain Tensor along the X-component is shown in Fig. 9.

Strain Tensor (Y-component) is demonstrated in Fig. 10.

The strain tensor analysis (Z-component) are shown in Fig. 11.

The Pressure characteristics with the temperature variations are demonstrated in Fig. 12.

The Stress Characteristics are shown in Fig. 13.
The analysis of the Von mises stress proves to be useful for the determination of the yield of the actuator when subjected to complex loading conditions. At higher temperatures the phase transformation brings a variation in the Von mises stress across the actuator. The simulation results for the Von mises stress are demonstrated in Fig. 14.

![Stress Characteristics](image)

Figure 13. The stress characteristic curve under the phase transformation with increasing temperature

VI. VONMISESSTRESS CHARACTERISTIC

The characteristics of the Nitinol microactuator were precisely studied and modeling of these characteristics was verified using COMSOL Multiphysics 4.4. The characteristics curves were plotted for these parameters with variances in temperature. The dependence of these characteristics on the shape memory behavior during the phase transformation is demonstrated using FEM analysis on this cantilever microactuator and the mathematic model was proposed for these parameters. The characteristics obtained indicate the effectiveness of the Nitinol in the field of microactuation.

VII. SUMMARY

The Von mises stress with the variations in temperature are shown in Fig. 15

REFERENCES


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