CHAPTER THREE

ELECTROSTATIC ACTUATOR DESIGN

3.1. Introduction:

Electrostatic actuator NEMS device is combining three fields electrical, thermal and mechanical structural. It is generally consist of four main parts:

1. Base layer.
2. Isolator layer.
3. Actuator layer.
4. Pad layer.

3.1.1. Base layer:

This layer used for two purposes the first one is to complete the electrical circuit by being the ground of the circuit, also this layer used as a base to carry the other parts of actuator. It is made of semi-conductors, either silicon semi-conductors, or any other, the dimensions of this layer are (200×2×20) µm.

3.1.2. Isolator layer:

This one is located between base and actuator layers, it has specific function which is the isolating the electrical current this makes voltage difference between base and actuator layers by this difference the actuation takes place. This layer is made either of silicon dioxide (SiO2) or any other isolator; the dimensions of this layer are (50×3×20) µm.
3.1.3. Actuator layer:

This layer is located on isolator layer between isolator and pad layers. This layer is the most important layer as it controls actuator characteristics. It is made of semi-conductors, either silicon, or any other semi-conductors. The dimensions of this layer are $(200 \times 2 \times 20) \mu m$.

3.1.4. Pad layer:

This layer is placed at the top of the actuator; on its surface the main electric supplier is attached. It is made of material which has high electrical conductivity such as copper, silver, and aluminum. The dimensions of this layer are $(200 \times 2 \times 20) \mu m$.

3.2. The programming:

After selection structural, thermal, and electric as references, ANSYS program has three major steps for analysis:

3.2.1. Pre-process:

This section of the program includes:

3.2.1.1. Element type:

Element type represents the required shape of the element. It is specified by the mesh dimension either 1D, 2D, or 3D. It is governed by the analysis field, solid 227 has been used as element type.

3.2.1.2. Material properties defining:

ANSYS treats the material according to its properties which makes the definition of material properties accurately. It is very important to have good results. The following table shows the material properties:
Table (3.1) Material properties used in Design

<table>
<thead>
<tr>
<th>material</th>
<th>Elastic Modules (MPa)</th>
<th>Poisson's Ratio (PR)</th>
<th>Density (Kg/µm³)</th>
<th>Thermal Expansion Coefficient (α),1/ºc</th>
<th>Thermal Conductivity (K),pW/µmºc</th>
<th>Resistivity (R) (ohm-µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SI</td>
<td>$185e^3$</td>
<td>0.28</td>
<td>$23e^{20}$</td>
<td>$2.33e^{-6}$</td>
<td>$157e^6$</td>
<td>$64e^{-4}$</td>
</tr>
<tr>
<td>SIO2</td>
<td>$73e^3$</td>
<td>0.23</td>
<td>$22.7e^{20}$</td>
<td>$0.5e^{-6}$</td>
<td>$1.4e^6$</td>
<td>$1e^{14}$</td>
</tr>
<tr>
<td>CU</td>
<td>$110e^3$</td>
<td>0.34</td>
<td>$89e^{20}$</td>
<td>$16.56e^{-6}$</td>
<td>$393e^6$</td>
<td>$1.72e^{-14}$</td>
</tr>
</tbody>
</table>

3.2.1.3. Geometry:

ANSYS provide two methods for geometry by importing it from drawing programs or by drawing in ANSYS, The following Figure (3.1) is show the drawn geometry.
3.2.1.4. Mesh:

FEM works on dividing the model to small elements, this element are divided by many points which named as nodes. Nodes are considered as center of element and all parameters are calculated, this whole process is termed as mesh. ANSYS meshes each part of actuator separately with it specific properties, this process is termed as attributed mesh, the shape of mesh is selected as (tetra) and the size of element is selected by ANSYS APDL as default. The following Figure (3.2) shows attributed mesh.
3.2.2. Solution:

A- Analysis Type:

In this part of program you have to select your type of analysis, that depend upon which parameter you want to preview, in this research static and modal analysis was selected as analysis type.

B- Load Definition:

In this stage both electrical and structural loads are applied. The following Figure (3.3) represents geometry with applied load.
Figure (3.3): Geometry with Applied load

C- Solve:

This part in the program like RUN, that executes all the commands and parameters which entered.

3.2.3. Post process:

In this part the program allows to the user to plot the results of analysis, which will be showed in chapter four.
3.3. Effect of the Electrode Position on the Natural Frequency:

It was compare the natural frequency which has been calculated by analytical method with that one which has been calculated by ANSYS.

Modal Validation:

Natural frequency by analytical methods given by:[2].

\[ f = 0.16 \times \frac{t}{l^2} \times \sqrt{\frac{E}{\rho}} \text{ Eq. (3.1)} \]

\[ f = \text{Natural frequency (Hz).} \]

\[ E = \text{Elasticity modulus (Pa).} \]

\[ \rho = \text{Density (kg/m}^3\text{).} \]

\[ t = \text{thickness (m).} \]

\[ l = \text{length (m).} \]

\[ E_{eq} = \frac{\sum l}{\sum_{i=1}^{2} \frac{E_i}{l_i}} \]

\[ E_{eq} = 137.966 \times 10^9 \text{ N/m}^2 \]

\[ \rho_{eq} = n\rho_1 + (1-n)\rho_2 = 5600 \text{ kg/m}^3 \]
3.3.1. Natural frequency by analytical methods for 100% of cantilever covered with electrode pad: (L=200µm)

\[ f = 0.16 \times \frac{0.004 \times 10^{-3}}{[0.2 \times 10^{-3}]^2} \sqrt{\frac{137.966 \times 10^9}{5600}} \]

\[ = 79.4167 \text{ KHz} \]

3.3.1.1. Natural frequency by ANSYS for 100% of cantilever covered with electrode pad show in Figure (3.4):

![Figure (3.4): Natural frequency by ANSYS for (L=200µm)](image)

Notice that the value of natural frequency is 78.1238 KHz.

Error in frequency:-

\[ \Delta f = \frac{f_{\text{analytical}} - f_{\text{ansys}}}{f_{\text{analytical}}} \]
From this calculation was found that the error as percentage is 1.628% and this refers to the accuracy of formula used by ANSYS to calculate the natural frequency.

### 3.3.2. Natural frequency by analytical methods when (L=180µm):

\[
E_{eq} = 139.8373 \times 10^9 \text{ N/m}^2
\]

\[
f = 0.16 \times \frac{0.004 \times 10^{-3}}{[0.18 \times 10^{-3}]^2} \sqrt{\frac{139.8373 \times 10^9}{5600}}
\]

\[
= 98.708 \text{ KHz}
\]

### 3.3.2.1 Natural frequency by ANSYS when (L=180µm) show in Figure (3.5):

![Figure (3.5): Natural frequency by ANSYS for (L=180µm)]
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Notice that the value of natural frequency is 100.799 KHz.

**Error in frequency:-**

\[
\frac{100.799 - 98.708}{100.799} = 0.02074 = 2.074\%
\]

From this calculation was found that the error as percentage is 2.074% and this refers to the accuracy of formula used by ANSYS to calculate the natural frequency.

### 3.3.3. Natural frequency by analytical methods when (L=160µm):

\[
E_{eq} = 141.9767 \text{ N/m}^2
\]

\[
f = 0.16 \times \frac{0.004 \times 10^{-3}}{[0.16 \times 10^{-3}]^2} \times \sqrt{\frac{141.9767 \times 10^9}{5600}}
\]

\[
= 125.879 \text{ KHz}
\]

### 3.3.3.1 Natural frequency by ANSYS when (L=160µm) show in Figure (3.6):

![Figure (3.6): Natural frequency by ANSYS for (L=160µm)](image-url)
Notice that the value of natural frequency is 145.563 KHz.

Error in frequency:-

\[
\frac{145.563 - 125.879}{145.563} = 0.1352 = 13.52\%
\]

From this calculation was found that the error as percentage is 13.52% and this refers to the accuracy of formula used by ANSYS to calculate the natural frequency.

3.3.4. Natural frequency by analytical methods when (L=140µm):

\[
E_{eq} = 144.4468 \text{ N/m}^2
\]

\[
f = 0.16 * \frac{0.004 * 10^{-3}}{[0.14 * 10^{-3}]^2} * \sqrt{\frac{144.4468 * 10^9}{5600}}
\]

\[= 165.837 \text{ KHz}\]

3.3.4.1 Natural frequency by ANSYS when (L=140µm) show in Figure (3.7):

![Figure (3.7): Natural frequency by ANSYS for (L=140µm)](image_url)
Notice that the value of natural frequency is 149.002 KHz.

**Error in frequency:-**

$$\frac{165.837-149.002}{165.837} = 0.1015 = 10.15\%$$

From this calculation was found that the error as percentage is 10.15% and this refers to the accuracy of formula used by ANSYS to calculate the natural frequency.

**3.3.5. Natural frequency by analytical methods when (L=120µm)**

$$E_{eq} = 147.3303 \times 10^9 \text{ N/m}^2$$

$$f = 0.16 \times \frac{0.004 \times 10^{-3}}{[0.12 \times 10^{-3}]^2} \sqrt{\frac{147.3303 \times 10^9}{5600}}$$

$$= 227.965 \text{ KHz}$$

**3.3.5.1 Natural frequency by ANSYS when (L=120µm) show in Figure (3.8):**

![Figure (3.8): Natural frequency by ANSYS for (L=120µm)](image-url)
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Notice that the value of natural frequency is **231.653 KHz**.

**Error in frequency:**

\[
\frac{231.653 - 227.965}{231.653} = 0.0159 = 1.59\%
\]

From this calculation was found that the error as percentage is 1.59% and this refers to the accuracy of formula used by ANSYS to calculate the natural frequency.

**3.3.6. Natural frequency by analytical methods when (L=100µm):**

\[
E_{eq} = 150.7407 \times 10^9 \text{ N/m}^2
\]

\[
f = 0.16 \times \frac{0.004 \times 10^{-3}}{[0.10 \times 10^{-3}]^2} \times \sqrt{\frac{150.7407 \times 10^9}{5600}}
\]

\[
= 332.048 \text{ KHz}
\]

**3.3.6.1 Natural frequency by ANSYS when (L=100µm) show in Figure (3.9):**

![Figure (3.9): Natural frequency by ANSYS for (L=100µm)](image)
Notice that the value of natural frequency is 328.204 KHz.

**Error in frequency:-**

\[
\frac{332.048 - 328.204}{332.048} = 0.0116 = 1.16\%
\]

From this calculation was found that the error as percentage is 1.16% and this refers to the accuracy of formula used by ANSYS to calculate the natural frequency.

### 3.3.7. Natural frequency by analytical methods when (L=80µm):

\[
E_{eq} = 154.8370 \times 10^9 \text{ N/m}^2
\]

\[
f = 0.16 \times \frac{0.004 \times 10^{-3}}{[0.08 \times 10^{-3}]^2} \sqrt{\frac{154.8370 \times 10^9}{5600}}
\]

\[
= 525.827 \text{ KHz}
\]

### 3.3.7.1 Natural frequency by ANSYS when (L=80µm) show in Figure (3.10):

![Figure (3.10): Natural frequency by ANSYS for (L=80µm)](image_url)
Notice that the value of natural frequency is \(556.157\) KHz.

**Error in frequency:-**

\[
\frac{556.157 - 525.827}{556.157} = 0.05453 = 5.453\%
\]

From this calculation was found that the error as percentage is 5.453% and this refers to the accuracy of formula used by ANSYS to calculate the natural frequency.

### 3.4. Natural frequency Simulation Results:-

The below table shows gained results:

**Table (3.2):** Natural frequency result

<table>
<thead>
<tr>
<th>% of cantilever covered with Electrode pad</th>
<th>Electrode Length(µm)</th>
<th>Natural Frequency(KHz) By ANSYS</th>
<th>Natural Frequency(KHz) By Calculation</th>
<th>Error for Natural Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>200</td>
<td>78.1238</td>
<td>79.4167</td>
<td>1.628</td>
</tr>
<tr>
<td>90</td>
<td>180</td>
<td>100.799</td>
<td>98.708</td>
<td>2.074</td>
</tr>
<tr>
<td>80</td>
<td>160</td>
<td>145.563</td>
<td>125.879</td>
<td>13.52</td>
</tr>
<tr>
<td>70</td>
<td>140</td>
<td>149.002</td>
<td>165.837</td>
<td>10.15</td>
</tr>
<tr>
<td>60</td>
<td>120</td>
<td>231.653</td>
<td>227.965</td>
<td>1.59</td>
</tr>
<tr>
<td>50</td>
<td>100</td>
<td>328.204</td>
<td>332.048</td>
<td>1.16</td>
</tr>
<tr>
<td>40</td>
<td>80</td>
<td>556.157</td>
<td>525.827</td>
<td>5.453</td>
</tr>
</tbody>
</table>

- The above table shows the natural frequency by both (ANSYS & Calculation) and error between them for different positions of the electrode Pad; the errors shown are different for different positions, because the mesh of geometry in ANSYS is different in each design.