Research on Modeling and Design of Rotation and Translation Ultrasonic Motors

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Abstract: - The paper presents the analytical and finite element method for modeling of a linear and rotating ultrasonic motor .
Key-Words: - Ultra acoustic, Finite element method, Piezoceramic, Transducer, Motors

1 General Considerations

Mathematical modeling of an ultrasonic motor used in robotics or micro-robotics or other applications can be done in tow ways [1], [2].

Fist, there is the theory of finite elements that could describe the reactions of the active pieziceramic element and/or the activated element.

Secondly, it is the analytical method that conduces to the mathematical description of the movement indicated by the active element, the activated one and the zone of contact between the tow of them. The description that this equations make is incomplete because of the multiple points of interrelation and the solutions for this sets of equations is almost impossible.

For the mathematical modeling of an ultrasonic motor is necessary to follow the next criteria:
- possibility of controlling separately the vibration amplitude in every direction;
- possibility of realizing every faze difference between the oscillations of the components;
- possibility of realizing a controlled mechanical contact between the active piezoceramic element and the mobile active element;
- existence of common vibrations modes in all oscillating components [10], [11].

2 Mathematical Modeling

In the dynamic analysis of the active piezoceramic elements is necessary to consider the mechanical, electrical phenomenon and the interaction between them.[8], [9], [16]. Therefore the state of every element used in this method can be represented – see figure 1 - by the values of the nodal displacement u, and the electric potential, φ:

$$u = [N]U^e \quad (1)$$

$$\varphi = [L]\Phi^e \quad (2)$$

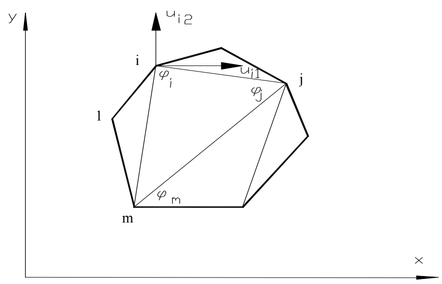

Fig. 1 The discretisation in finite elements of an area in a piezoceramic material

where: [N] and [L] are, in general, position functions;
U^e; Φ^e – nodal displacement and respective, potential.

If the displacement are known in every point of the structure, using the finite element analysis, we can find the expression of the displacement ε_i, for each i point, of the structure by elastic theory equation:

$$\varepsilon_i = [B]U^e \quad (3)$$

Because the link between the electrostatic force E and the potential is given by:

$$E = -\mathrm{grad}\varphi \quad (4)$$

the value of the electric field E, in every point of the structure can be represented by (3) that is similar to (4), so:

$$E = -[B_E]\Phi^e \quad (5)$$

The equations of the piezoceramic effect for the elementary volume are given by:

$$\left.\begin{aligned} \sigma &= \left[c^E\right]\varepsilon - [e]E \\ D &= [e]^T\varepsilon + \left[\ni^S\right]E \end{aligned}\right\} \quad (6)$$

where : σ are the mechanical efforts –electrical polarization vector;

$[C^E]$ –the rigidity meter for a constant electrical field;

[e] – piezoceramic constant meter;

$\left[э^S \right]$ is the meter for the dielectric constants at a constant deformation.

Replacing (3) and (5) for every point of the finite element the equations turns into:

$$\sigma = \left[c^E \right][B]U^e + [e]\left[B_E\right]\Phi^e$$
$$D = [e]^T[B]U^e - \left[э^S \right]\left[B_E\right]\Phi^e \qquad (7)$$

We can assume the external force f, is known in every point of the structure and one or many nodes on the surface of the structure are connected to the electrodes[13], [14].

The loads concentrate in this nodes are represented by the vector Q^e. Equations of equilibrium for finite element can be derived by matching mechanical internal and electromagnetically and external work force, and the nodal points can make virtual displacements δ_n and virtual and potential loads δ_φ. The virtual modifications in the material δ_ε and the electrical field δ_E can be calculated by :

$$\delta_\varepsilon = [B]\delta U^e$$
$$\delta E = -[B_E]\delta\Phi^e \qquad (8)$$

Transforming the nodal variables, by integrating the volume of elementary volumes V_e and equaling the internal and external working forces is obtained :

$$\int\left(\delta\varepsilon^T\sigma + \delta E^T D\right)dV + \delta\Phi^{eT}Q^e = \int\delta U^T f dV \qquad (9)$$

or

$$\int_{V^e}\left[\left(\delta U^e\right)^T\left([B]^T\left[c^E\right][B]U^e + [B]^T[e][B_E]\Phi^e\right) - \right]dV +$$
$$\delta\Phi^{eT}Q^e = \int_{V^e}\left(\delta U^e\right)^T[N]f dV \qquad (10)$$

Because δU^e and $\delta\Phi^e$ can be arbitrary, equation (10) is divided in to equations :

$$[K^e]U^e + [T^e]\Phi^e = F^e$$
$$[T^e]\,U^e - [S^e]\Phi^e = Q^e \qquad (11)$$

In relation (9) equations the matrix of the finite element can be written as follows:

- the rigid matrix $[K^e]$:

$$\left[K^e\right] = \int_{V_e}[B]^T\left[c^E\right][B]dV\ ; \qquad (12)$$

- the electromagnetically matrix $[T^e]$:

$$\left[T^e\right] = \int_{V^e}[B]^T[e]\left[B_E\right]dV\ ; \qquad (13)$$

- capacity matrix $[S^e]$:

$$\left[S^e\right] = \int_{V^e}\left[B_E\right]^T\left[\partial^S\right]\left[B_E\right]dV \qquad (14)$$

And the vector of nodal forces F^e can be determined with:

$$F^e = \int[N]^T f dV \qquad (15)$$

As we can see in relation (11), there can be many unknown dimensions related to the equations because in a general case the loads in the nodal points are unknown. This is why we must insert limit conditions. Mechanic limit conditions must be clear and there introduction in the equations can be described in the bibliography of finite elements, but the electrical limit conditions must be examined carefully. By example if the finite element doesn't have a electrode on the surface then the limit conditions for the nodes is zero load. When an electrical tension is applied on the surface of the electrode from an tension source that is powerful (U= 50...300 V, I ≤ 1A), we can consider that the potential in finite element is specified. Consideration of such limit conditions that permits the number of unknowns to be equal to the number of equations and thus we can solve equations (11).

3 Modeling of Ultrasonic Motors

For modeling an ultraacustic motor with multiple freedom degrees is necessary to determine the vibration modes for the active element [1], [2], [3].

Knowing the vibration modes of the piezoceramic elements can determine the ease of designing piezoceramic motors and also, we can shorten the time that is necessary for the experiments choosing the vibration modes, that corresponds to certain vibration fervencies that are capable to produce the movement of the activated element.

In this way it is no longer necessary to go through the ultrasonic domain (f = 18kHz…150kHz) and we can observe the fervencies of the active element of the ultrasonic motor it is starting to vibrate and especially we will tray the fervencies in which the shape of the vibration is obtained through the method of the finite element and is optimum for the process of determining the vibration modes of an piezoceramic element.

In the first framework named "Preprocessor" in the first stage we will be to chose a type of analysis that will be realized, a structural analysis.

In the next step, that is crucial in the definition of finite elements, we will choose de element for the studied structure. We will choose with the help of the "**Element Type**" command a element "**Coupled field**" named "**Scalar Tet 98**". Because of the proprieties this element can transform the electric charge applied to the piezoceramic material in a deformation.

The third step, a very important step in this type of analysis, is the determination of the mechanical proprieties of the piezoceramic material. For this we will select the commands "**Material proprieties**"-"**Material Modes**".

In the next step we will describe the geometry of the piezoceramic element. The piezoceramic element is a disc and has the following dimensions: interior diameter d=6 mm; exterior diameter D=32mm and thickness h=2,5 mm. For the realization of the chosen structure we will use the commands "**Modeling-Create-Volumes-Cylinder-Hollow Cylinder**".

The characteristic of the finite element method is the discretization of the studied structures in capable components that characterize the studied phenomenon components. For this we will use the commands "**Meshing-Mesh-Volumes-Free**" and we will select with the mouse the geometry or we will push the "Pick All" button.

Because the analysis that we have presented refer to the piezoelectric phenomena studies, the definition of the initial work conditions mean the applicability of a difference of potential on the tow surfaces of the piezoceramic disk. This means in Ansys format the following set of commands "**Apply-Electric-Voltage-On Areas**".

If we apply a tension U=150 V on one surfaces of the piezoceramic disc, than on the other surface we will apply a tension of U=0 V.

Determining the proper vibration method of the pieziceramic cylinder is made by selecting the modal analysis option from the "**Solution**" module.

The frequency of f=63466 Hz can be considered as the first frequency for simulating the displacement of the ultrasonic motor's activated mobile element– see figure 2.

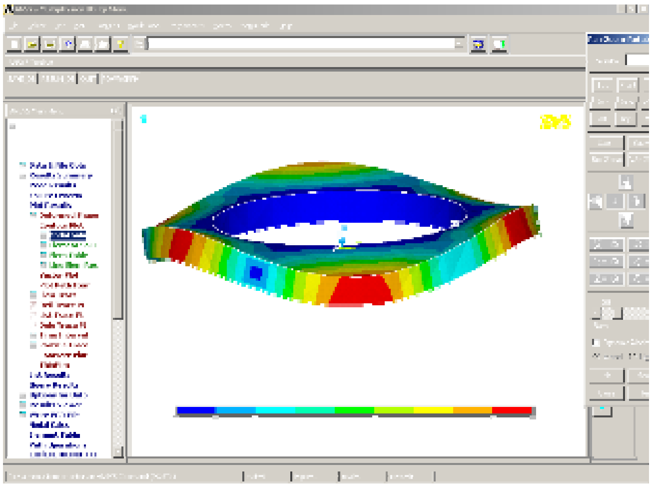

Fig. 2 "Traveling" type oscillations at a frequency of f = 63466 Hz.

In this case there are three minims and three maxims of deformation. From a theoretical point of view, the "traveling" type oscillations appear, problem that must be resolved being the capacity if these points, numbering four and that can produce friction forces that are sufficient to produce the rotation of the activated element [8], [12], [14].

The number of minimum and maximum points increases to five for a frequency of f=85518 Hz, in which the realization of the rotation is very possible. As shown in the figure 3, the oscillations are perfectly symmetrical and the number of the maximum and the minimum can be obtained, from practical, real point of view. Should be mentioned that a higher number couldn't, in real cases, be realized, because of piezo-ceramic material's rigidity point of view.

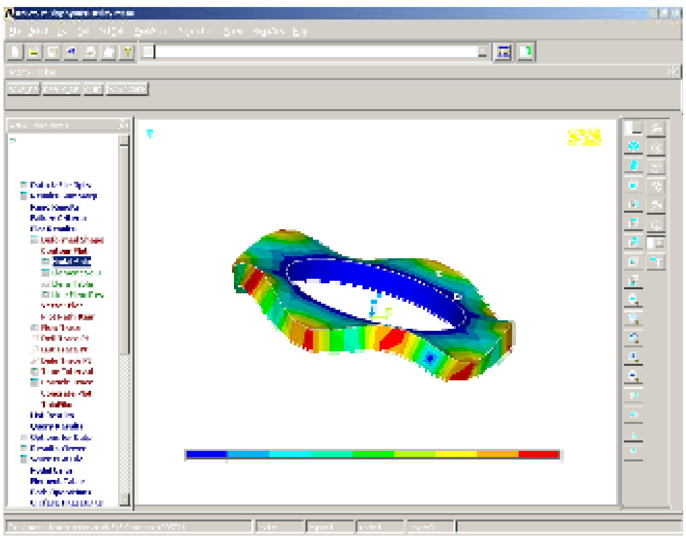

Fig. 3 "Traveling" type oscillations at a frequency of f = 85518 Hz.

4 Conclusion

1. For an efficient design of an ultrasonic motor we must first make a model that can solved with the method of finite element analysis and the Ansys program package;

2. Thought the modeling that uses the analytical method with finite element we can determine fast the vibration modes for every form of active piezoceramic element;

3. For an active piezoceramic disk with a certain geometry we can determine the vibration modes in which the "travelling" type movement can permit the realization of a certain rotation movement for the activated element, around his axes, at a fervency of f=85518 Hz with six maxims of oscillations and at a fervency of f= 85949 with six maxims of oscillations;

4. The modal analysis and the determination of the vibration modes in which the "Travelling" type vibration appear in the active element, can allow a efficient design of the active and the activated elements of a ultrasonic motor, can reduce the use of materials and the time of experimenting.

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