Numerical Investigation of Dynamical Properties of Vibroactive Pad

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Abstract. The operating frequencies of the vibroactive pad used in order to improve the quality of replicas of complex microstructures during the mechanical hot imprint process, are numerically analyzed in this paper. It is known that piezoceramics changes its dynamical properties under the action of mechanical load. It is necessary to investigate dynamical properties of vibroactive pad, in order to improve the quality of replicas when planning more detailed research and development in this field in the future. Experimentally there is no possibility to determine the natural frequency for the construction to be excited, in order to reach the same modes of forms, thus modeling of the process was performed. The created mathematical model of vibroactive pad was implemented by FEM using *COMSOL Multiphysics* software.

1. Introduction

The exceptional potential of hot imprint technology like: low cost, easy implementation and ability to obtain high resolution are the main reasons to further investigate, establish and apply such manufacturing capabilities. The basic principle of hot embossing composes from following major steps: first of all polymer substrate is heated above its glass transition temperature. Then a mold (or master) is pressed against the substrate. Lastly, the system is cooled down below glass transition temperature, and the embossed substrate is demolded from the tool.

On the other hand there is necessity to study the risk of formed microstructure potential defects, which can occur as the result of material melting and releasing of the structure from the mold. These defects include material shrinkage, visible cracks, etc.

One of the ways to improve the quality of replicas can be usage of high-frequency vibrations in the process of mechanical hot imprint.

Ultrasonic vibrations [1-4] are widely applied in industrial processes, especially in welding and joining of thermoplastic with low softening temperature.

The ultrasonic energy is converted into heat because of the intermolecular friction within the thermoplastics. The highest temperature between the surfaces of master mold and the plate due to asperities is high enough in order to melt thermoplastics. For this reason melted thermoplastic becomes fluid-like and fills the interface between two surfaces. Ultrasonic vibration is as an efficient technique for heat generation, in order to imprint the precise structure onto the large surfaces [5].

As it is revealed high frequency vibrations can be used as a measure to improve the quality of replicas [6], on the other hand it is necessary to know working regimes of the equipment, which generates such vibrations, in this case working regimes of vibroactive pad. To perform such an analysis experimentally would lead to higher time and money expenses, so it was decided in this paper to create model of vibroactive pad and analyze this pad using Comsol Multiphysics software [7-8].

2. Finite element model of vibroactive pad

Modeling of vibroactive pad used in hot imprint process as frequency generator is presented in this section.

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Aluminum cylinder with the top surface and a mounting hole in the side wall was chosen as a vibrating pad. The geometrical drawing of the vibrating pad with the mounted piezoelectric element is shown in the Fig. 1.

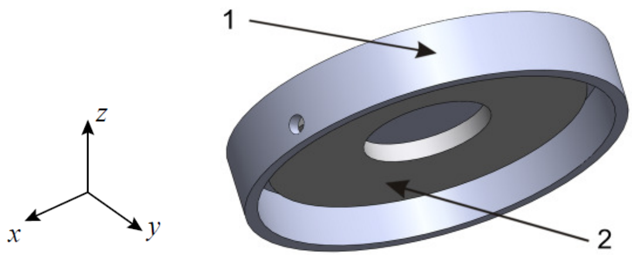


Figure 1. The 3D view of the pad (1) with the piezoelectric element (2).

The applicability of vibroactive pad in the process of hot imprint was analyzed numerically using finite element method. The dynamic parameters of the vibroactive pad (Fig. 2) were calculated using program COMSOL Multiphysics 3.5a.
The geometrical parameters of vibroactive pad are as following: pad thickness (h_{Al}) is 2mm, thickness of piezo ceramic ring h_{PZT} is 3mm, and total height of the vibroactive pad h is 10mm. It is necessary to determine boundary conditions and initial value of the parameters of the model. Vibroactive pad's bottom surface is fixed (Fig. 2). Potential difference Q according to the experimental results between the upper and the lower piezoceramic ring surfaces vary from 5 to 150V. The computational scheme of vibroactive pad is presented in Fig. 2.

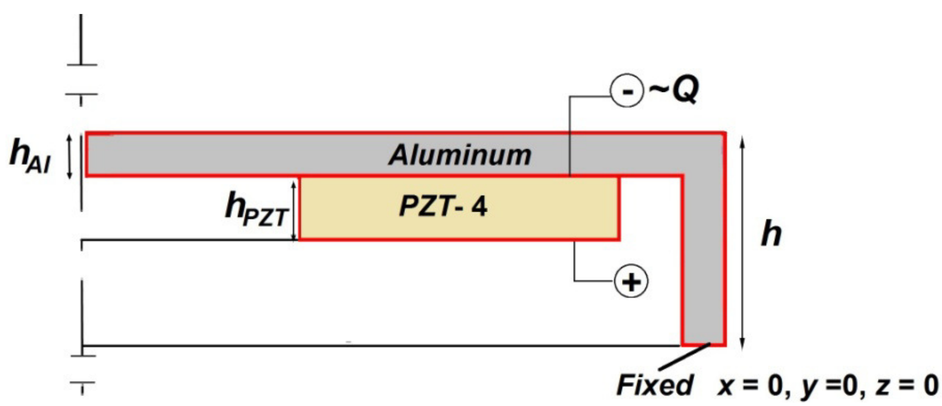


Figure 2. Computational scheme of vibroactive pad (displcement (u, v, w), thickness of vibroactive pad (h_{Al}), thickness of piezo ceramic ring (h_{PZT}) and height of vibroactive pad (h)).

The pad's material is aluminum (D16) and the disk is modeled as a piezo ceramic material PZT-4. The PZT-4 material's and aluminum's parameters were determined as in experimental.

Quadratic tetrahedral finite element (which has ten nodes and four dependent variables in each node (displacements in u, v, w directions and voltage Q)) was chosen for modeling (Fig. 3).

The material parameters for the piezoelectric material were specified according to: selecting the stress-charge form based on the constitutive equation and entering the material data (the elasticity-matrix elements in the c_E matrix, the piezoelectric coupling-matrix elements in the e matrix, and the relative permittivity in the ε_{rS} matrix).

The material properties in this model were set considering that the polarization is in the z direction, which is a common orientation, according to the literature.

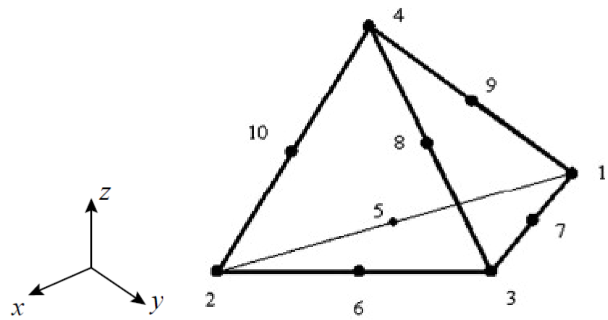
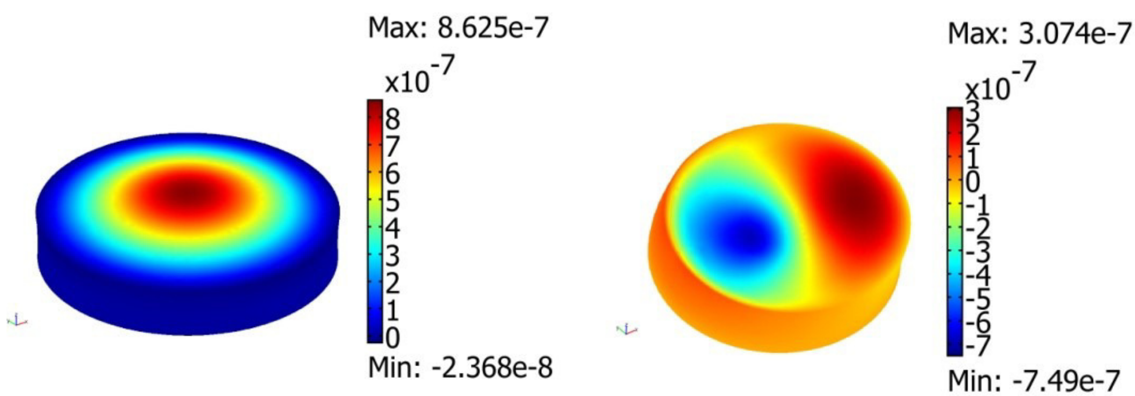


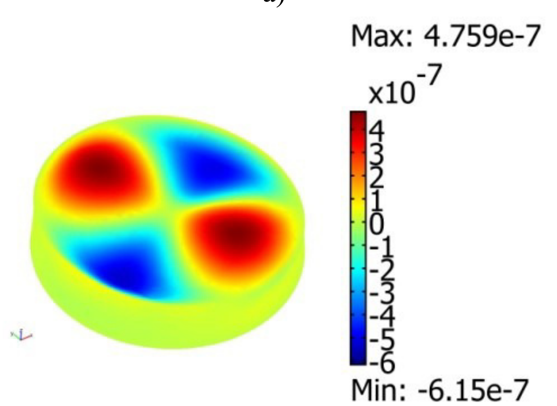
Figure 3. Tetrahedral finite element [9].

3. Results

Numerical simulation results of vibroactive pad working in different regimes are presented in Fig. 4.



a) b)



c)

Figure 4. Vibration modes of vibroactive pad:
(a) 5.8kHz and 10V,
(b) 9.5kHz and 60V,
(c) 19.3kHz and 70V.

As seen in pictures above, first three vibration modes are obtained at these frequencies: 5.8; 9.5 and 19.3kHz. Operating voltages respectively are 10; 60 and 70V. As it should be, highest amplitude (0.86μm) at lower excitation voltage is obtained at first vibration mode, while amplitudes of the second and third mode are respectively 0.3 and 0.47μm.

Frequencies of modes of vibrations were compared in order to check the validity of vibroactive pad modeling results with experimental data. The comparison between the experimental research and simulation results (Fig. 4) shows that simulation results correspond with experimental results of vibroactive pad.

The next step of the future investigation is to find operating frequencies of the vibroactive pad, when it is under load of $5.06 \cdot 10^5$Pa.

4. Conclusions

In this paper vibroactive pad made from aluminum was numerically analyzed in order to determine its working regimes. Three vibration modes, natural frequencies and operating voltages of vibroactive pad were determined. First three natural frequencies of modeled vibroactive pad are as following: 5.8; 9.5 and 19.3kHz. Adequacy of vibroactive pad FEM was checked.

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