

Heat Energy Modelling of Travelling Wave Piezoceramic Ultrasonic Motor

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Abstract. This paper presents the method of determining and characterizing of a piezoelectric stator profile that applying in a piezoceramic ultrasonic motor with the consideration of heat generated. The piezoceramic ultrasonic motor is driven by the vibration of the piezoelectric element in order to ignite a motion. The harmonic and transient analysis of finite element method are used to predict the optimise operation frequency of the motor travelling wave. Then, a thermal analysis is conducted in order to analyse the heat distribution on the stator. The stator profile displacements with the variable temperature; 300, 360 and 450 K are analysed. The piezoceramic ultrasonic motor shows different longitudinal deflection with the increment of the temperature. Travelling wave optimization was found to be strongly dependent on the heat that generated by the piezoceramic.

1 Introduction

Motor is a device that driven by electromagnetic force which involve conversion of electrical energy to mechanical energy [1] while ultrasonic motor is a device that driven by piezoelectric vibrations to convert electrical energy to mechanical energy [2].

Ultrasonic motor consists of piezoceramic, electrode, stator and rotor as its components. The stator surface is coupled with piezoceramic and AC voltages are supplied to it through electrodes. The voltages displace the stator in an elliptical trajectory. In response to the stator displacement, the rotor rotates simultaneously [3].

The travelling-wave piezoelectric ultrasonic motor (TWUSM) has recently been attracting considerable attention due to the high torque compare to the volume ratio, long life span and high stability in use [4].

However, a lot of efforts are still required to produce a robust ultrasonic motor. In the earlier development of ultrasonic motor, heat generation is not considered [5]. To overcome the issue above, the factors that cause the heat generation are well studied and reported [6]. Mathematical modelling of the temperature distribution is established using three-dimensional finite element method [7]. Devos *et al.* prove that resonant mode working principal enable to minimise the heat dissipation [8]. However, the heat is still generated tremendously and need to be reduced effectively.

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In order to provide a complete model of ultrasonic motor, the research objective is set to model the ultrasonic motor stator with the considering of the heat generated. The top surface of the stator profile will be the main area to be focused and analysed.

Since the heat generated in ultrasonic motor is a huge issue, the way to reduce the heat is a big contribution to the area. The heat suppression of the piezoceramics is depending on the mechanical quality factor, Q . With a high mechanical quality factor, Q , less heat is generated and this parameter must be taken into consideration [9].

The heat that generated during the vibrations influences dielectric loss of piezoceramic material. The relation of the piezoceramic temperature, T with the dielectric loss is shown as below [10].

$$T = T_o + \frac{R}{U} \tag{1}$$

where T_o is the ambient temperature, R is the thermal resistance of the dielectric and U is the voltage supplied. The thermal resistant, R is numerically close to the temperature increment during the conversion into thermal energy.

The increment of the piezoceramics temperature is able to influence driving frequency, ω of the stator and the relation of both factors is given as:

$$\omega = \omega_o (1 - 1.03 \times 10^{-4} (T - T_o) + 0.77 \times 10^{-7} (T - T_o)^2)^{1/2} \tag{2}$$

where ω_o is a natural frequency. The heat that affects the frequency can influence displacement of the stator subjected to geometry and frequency that supplied [11].

2 Methodology of ultrasonic modelling

Structure of ultrasonic motor stator is designed by joining two types of materials. Bottom layer of the stator is a 1 mm thickness of piezoceramic which is and the top layer is a copper of 5 mm thickness. The copper material is designed with staged structure as depicted in Figure 1.

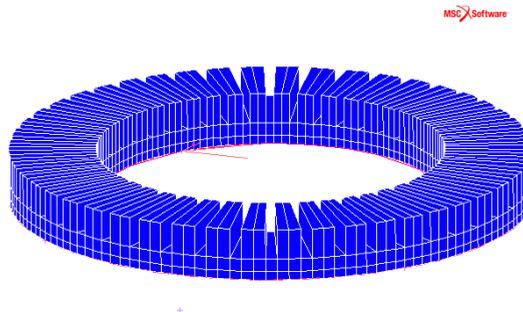


Fig. 1. The structure of the stator of ultrasonic motor.

Finite element analysis (FEA) is applied using MSC Marc Mentat software as a step to analyse the vibration characteristic. Computational aided design is developed by integrating 143 elements of piezoelectric material and 528 elements of 3-D solid. The elements are in hexagon shape.

The structure is analysed using harmonic mode analysis to identify the optimized frequency that provides the highest displacement on Z-axis. The range of the frequency is set from 1000 to 50000 Hz.

Then, the optimum frequency of the harmonic analysis is used as an input for transient analysis. The transient analysis is further preceded by providing two sinusoidal input functions which is shifted 90° from each other. The transient analysis is run for 3 ms to see the vibration profile of the top stator surface.

3 Results

Harmonic analysis of FEA enables to provide an optimum operation frequency in a form of mode shape for travelling wave ultrasonic motor. The optimum operation frequency predicted for this study is 40600 Hz and the mode shape of the stator is depicted in Figure 2.

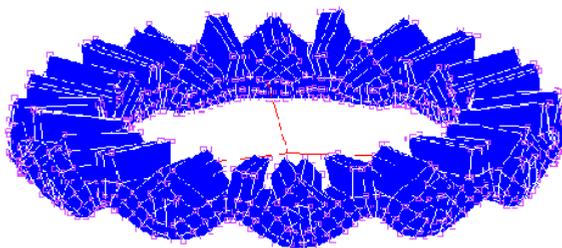


Fig. 2. The mode shape of the harmonic analysis given 40600 Hz of frequency.

The transient analysis at 40600 Hz is run to analyse the vibration of the top stator surface along the time. From this study, Z-axis displacements are found out and the displacement profile is shown in Figure 3.

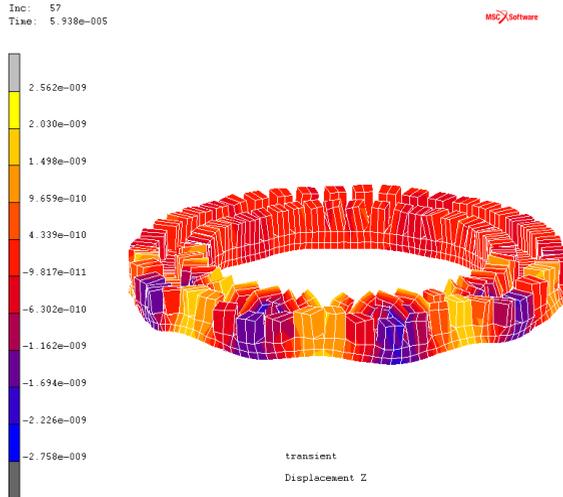


Fig. 3. The 57th over 300th iterations of transient analysis.

Profile of the top stator surface that drives the rotor is interested and the specific point at that surface is selected. Node 2303 is chosen for next analysis.

Figure 4 shows the profile of node 2303 at 300 K temperature. This condition which is close to room temperature is considered as the initial stage of the ultrasonic motor operation. The maximum displacement that perform in this condition by node 2303 is 2.117 nm.

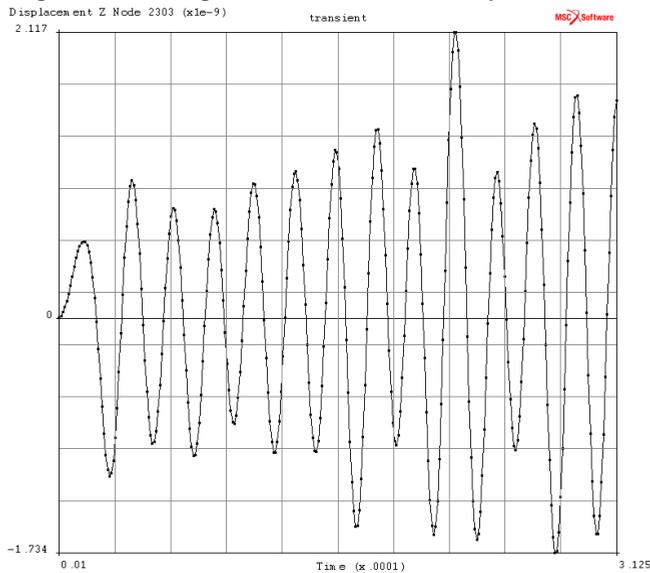


Fig. 4. FEA of Z-axis displacement for node 2303 at 300 K condition.

The analysis is continued for a temperature at 360 K, with the consideration of heat released by the piezoelectric material. The FEA found that the maximum displacement of node 2303 decreases rapidly to 0.5148 nm at 360 K condition as shown in Figure 5 due to the dielectric loss of piezoceramic.

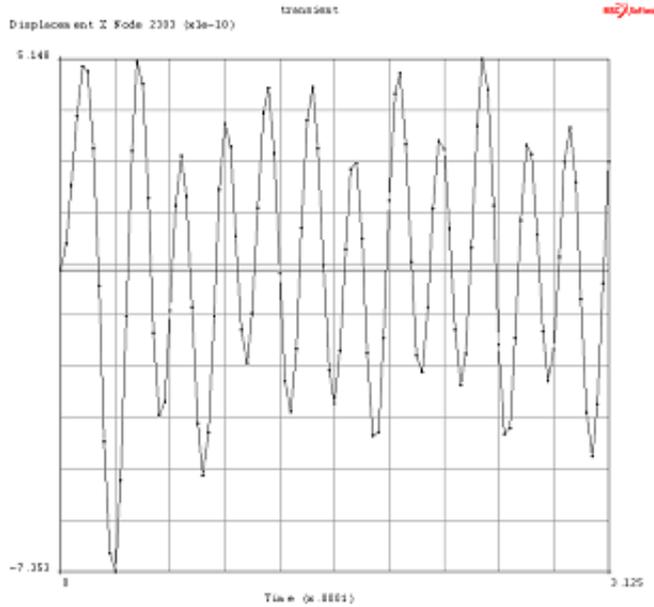


Fig. 5. FEA of Z-axis displacement for node 2303 at 360 K condition.

By using FEA, the maximum displacement drops down to 0.4547 nm as presented in Figure 6 when heats release by the piezoceramics increases the stator temperature to 450 K.

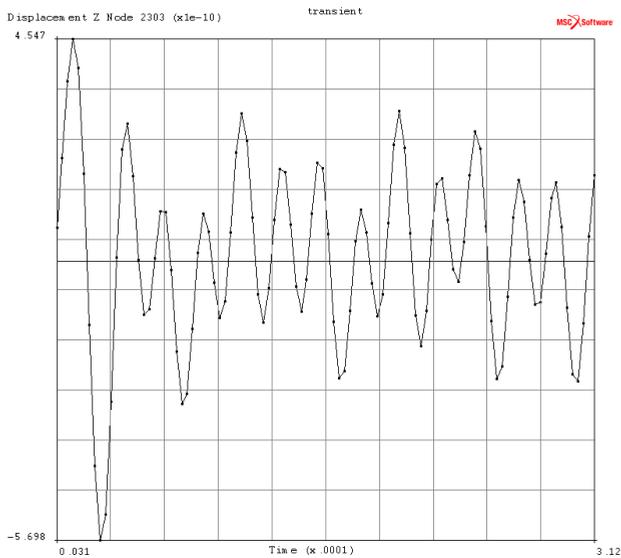


Fig. 6. FEA of Z-axis displacement for node 2303 at 450 K condition.

It is shown that the increment of the heat can influence the displacement profile of the ultrasonic motor stator. Reduction of the displacement profile mean the ultrasonic motor performance changed and this suppose to be avoided.

4 Conclusion

As the conclusion, the dielectric loss that converted into heat can significantly influence the Z-axis displacement. A better way of controlling the dielectric loss will determine the stator surface deflexion and directly contributed to the ultrasonic motor torque and speed improvement.

In order to gain the highest Z-axis displacement, the heat flux of the stator needs to be increase. By lowering the rate of the temperature increase, the ultrasonic motor can provide a better performance.

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