Multiphysics Simulation of an Ultrasonic Piezoelectric Motor

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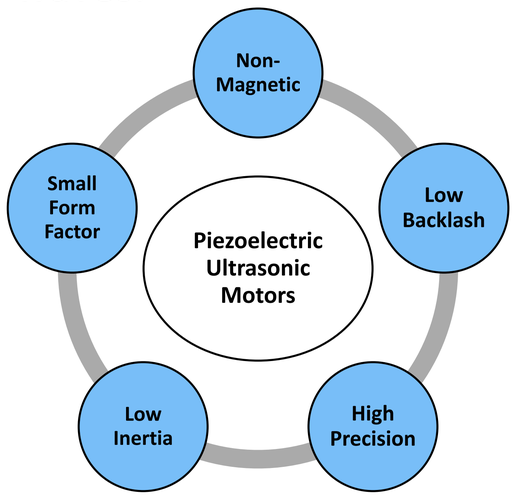
INTRODUCTION: Piezoelectric motors provide a suitable alternative where traditional actuators may be insufficient. We extend the work of [1] by simulating an ultrasonic traveling wave resonant motor based on the Shinsei Corporation USR30 (Japan) with a single mode electrode pattern that can be driven by two 90 degree shifted sine waves.



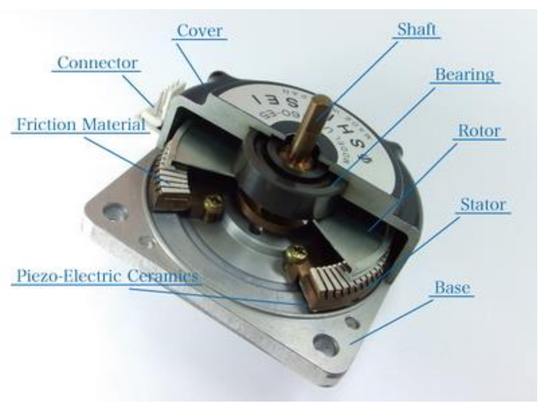


Figure 1. Cutaway view of a USR series Shinsei piezoelectric traveling wave motor [2].

OPERATING PRINCIPLES:

- Ultrasonic motors rely on the reverse piezoelectric effect to generate motive force.
- Traveling waves can be generated by sequentially exciting different portions of the ceramic element such that two interfering standing waves offset by pi/2 in both space and phase are created.

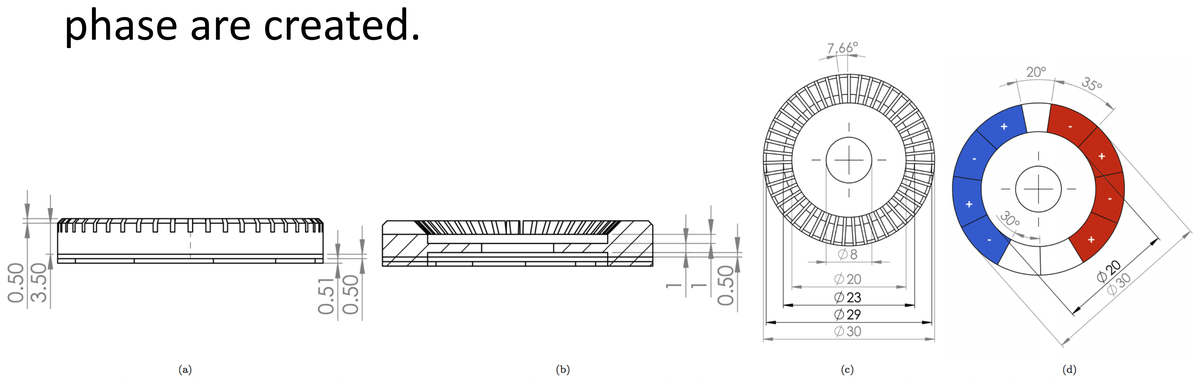
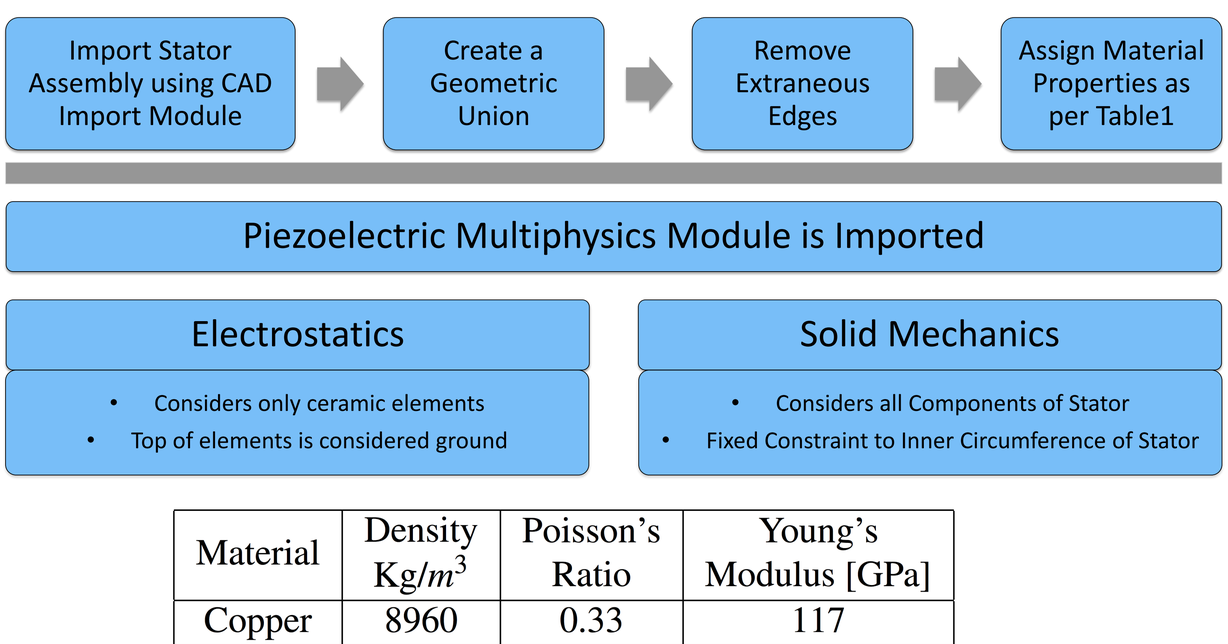


Figure 2. Schematic drawings of the modeled stator with bonded piezoelectric elements. (a) Side-View (b) Cutaway-View (c) Top-View (d) Bottom-View with electrode pattern

MODEL SETUP: Ultrasonic traveling wave resonant motors are comprised of a stator and a rotor. The USR30 stator was simulated using COMSOL 5.3a as per the following steps:



Material	Density Kg/m^3	Poisson's Ratio	Young's Modulus [GPa]
Copper	8960	0.33	117
Epoxy	3500	0.43	0.7
PZT-5H	7500	N/A	N/A

Table 1. Basic material properties for the three materials used in the simulation.

EIGENFREQUENCY STUDY: Determines the resonant modes of the stator. The mode corresponds to the shape the stator will assume if driven at a particular eigen-frequency.

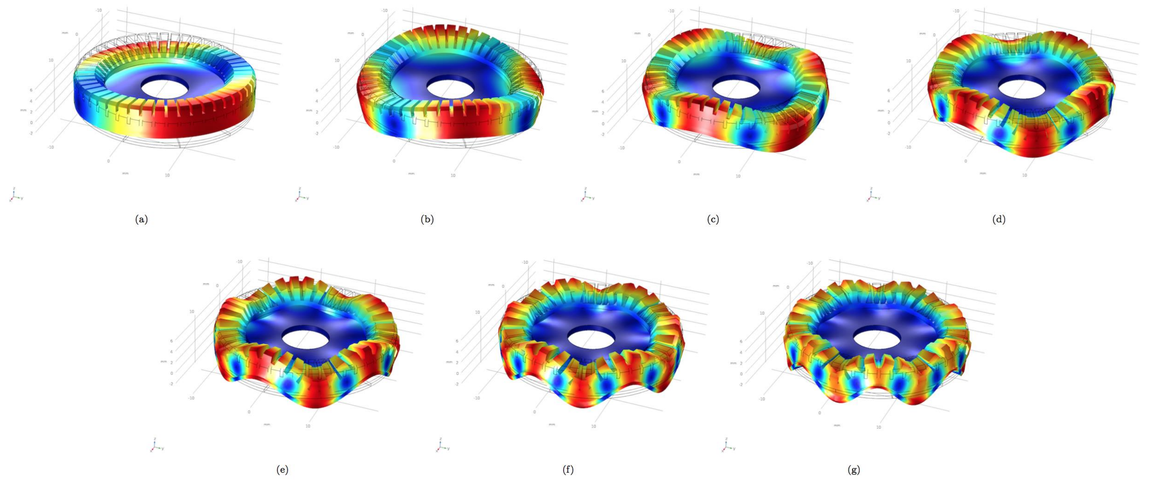


Figure 3. Results of eigen-frequency searching for 40 modes around 40 kHz. Relevant results shown above. (a) Mode 1 at 3.1 kHz (b) Mode 2 at 6.9 kHz (c) Mode 3 at 16.6 kHz (d) Mode 4 at 29.1 kHz (e) Mode 5 at 43.2 kHz (f) Mode 6 at 58.3 kHz (g) Mode 7 at 73.5 kHz

FREQUENCY DOMAIN STUDY: The results of a frequency sweep from 5kHz to 75kHz at 20 Hz increments is shown in Figure 4. The overall maximum displacement in the Z direction was observed to be 1.88 µm.

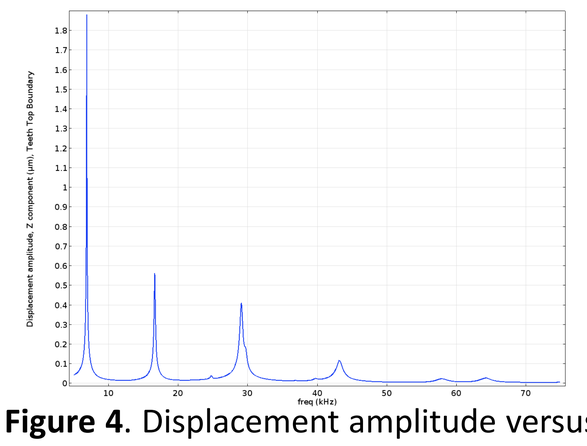


Figure 4. Displacement amplitude versus frequency. Resonant frequencies are noticeable

TIME DOMAIN STUDY: Settling time and tangential velocity were measured via boundary probes. The motor settles to a steady state within 1.6 ms. Under simplifying assumptions, the simulated motor has a rotational speed at resonance of approximately 120 rpm.

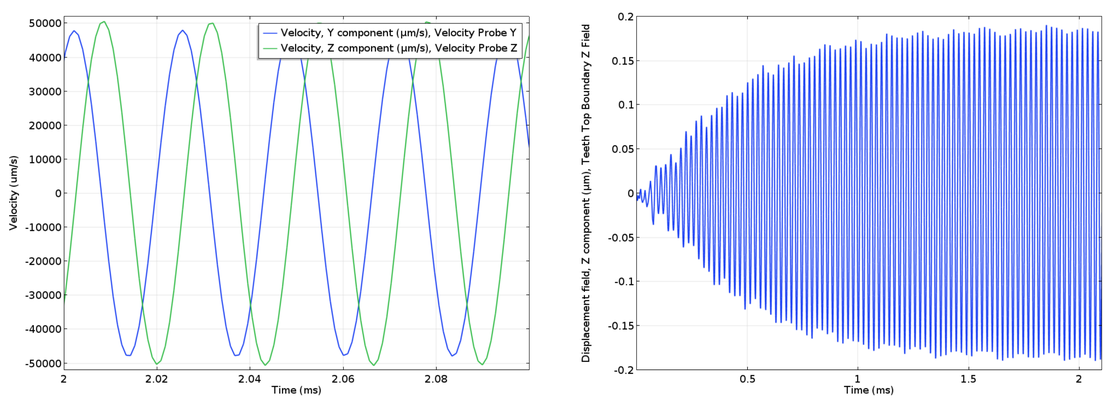


Figure 5. Results from the Time Domain Study showing settling time and tangential velocity of the stator at steady state.

CONCLUSIONS: A multiphysics model for a piezoelectric ultrasonic resonant motor is presented. Further work can include:

- modeling the rotor with frictional contact
- evaluating the damping parameters more precisely
- validating the model empirically through the measurement of modeled properties in a real motor.

REFERENCES:

1. Patel, P. & Manohar, P. Design and simulation of piezoelectric ultrasonic micro motor.
2. Ultrasonic motor. http://www.shinsei-motor.com/ English/techno/ultrasonic_motor.html. Accessed: 2018-08-31. (2009).