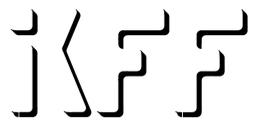


# Optimization of a Two-Contact Linear Ultrasonic Motor Using FEM-Analysis



## Introduction

The output power of ultrasonic motors increases with the number of frictional contacts and the magnitude of acceptable preload force. Thus high power devices driven with ultrasonic motors may be designed with multiple motors operating in parallel or with motors featuring multiple frictional contacts. Operation of two point contact single motors is challenging as optimum mechanical output can be expected only if the frictional contact engages simultaneously or alternately with equal speed and equal trajectories. A major benefit though is the reduced cost and a highly simplified overall design. Hereafter the use of a multiple mode bulk ceramic vibrator for the design of an ultrasonic motor is presented. The functional principle is based on the combination of the first longitudinal (L1) and second bending mode (B2).

## Configuration

Figure 1 shows the stator vibrator made of a high power piezoelectric ceramic block. Using a 5 mm thick plate with 60 mm length and 16 mm width high preload forces are acceptable.

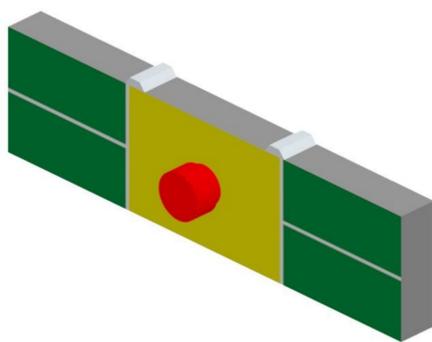


Fig. 1: Stator vibrator

Contact to the slider is established with two oxide ceramic bodies. The center of the block represents an overall nodal point and thus is suited to place a pin to mount the vibrator in a housing. Two symmetric electrode groups are placed on the surface of the vibrator.

## Functional Principle

Motor operation is based on the simultaneous excitation of the L1 and B2 mode. Figure 2 shows the elliptical trajectories as computed on the surface of the friction pieces.

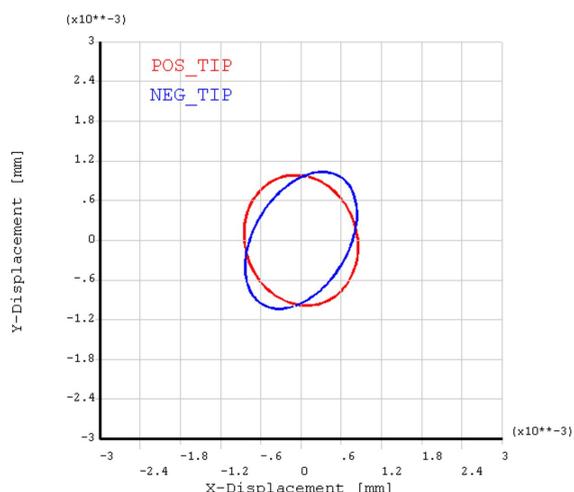


Fig. 2: Elliptic trajectories

The longitudinal mode drives the slider while the bending mode generates the necessary normal forces. Bending mode excitation is achieved using a diagonal connection of the green electrodes and linking the front electrode group and the back electrode group to generate mutually opposite contraction and expansion of the outside volumes of the vibrator. Highest mechanical output is obtained when resonance frequencies of both modes are equal. The influence of the friction pieces has to be considered. Optimum placement is achieved as shown in figure 2 when single mode excitation of B2 produces vertical displacement trajectories only. It is not possible, however, to obtain purely horizontal trajectories for the L1 mode at the same time. Longitudinal trajectories are slightly angled as a result of lateral contraction during oscillation thus small mutual rotation of the two trajectories is inherent to the design.

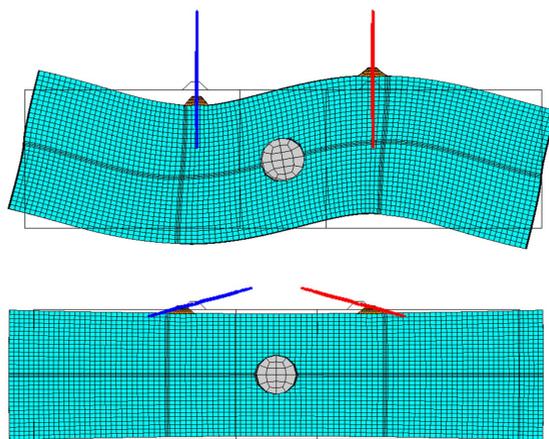


Fig. 3: FE model, B2 (top) and L1 (bottom)

A slight difference in the shape of the ellipses may be contributed to the pins mounted on the top and bottom surfaces of the vibrator. Rotation has no negative influence on motor characteristics as the phase shift of the excitation results in zero displacement and maximum velocity of the L1 mode while B2 assumes its maximum displacement position and engages mechanical contact. Thus during contact transport velocities effected on the slider will be equal and a continuous slider motion will be produced. Figure 4 shows the equivalent stress computed for an excitation of 60 V. Depending on preload driving voltage will increase due to higher damping.

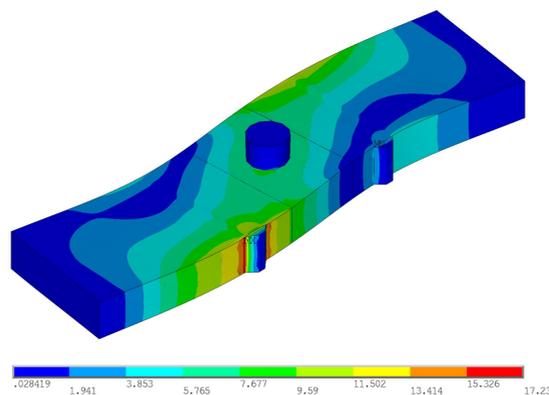


Fig. 4: FE model, computed stress

## Verification

In a slider setup as shown in Figure 5 the motor achieves a no-load speed of 225 mm/s and a blocking force of 13 N.



Fig. 5: Linear stage

To investigate electrical behavior a test bench as shown in Figure 6 was built. The frictional contacts engage with two separate wheels to allow measurements during continuous motor operation. Current is measured using a precision shunt resistor and data is sent to LABVIEW for analysis. Measurements are performed per phase.

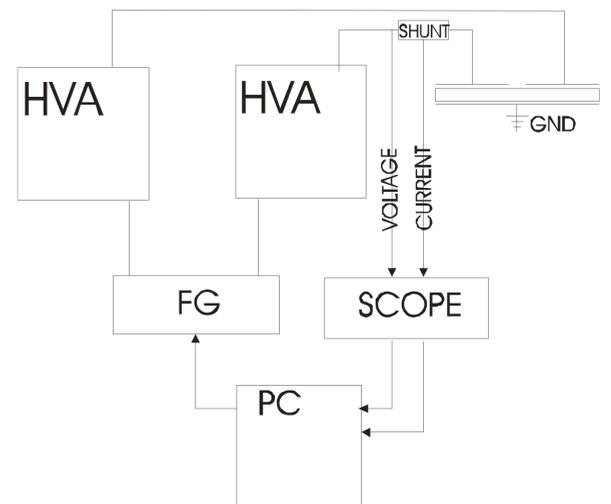


Fig. 6: Test bench

Due to preload computed resonance frequencies are shifted to lower values compared to computation (27440 L1 and 27420 B2). Impedance analyzer measurements on a freely vibrating stator resonator show a distinct frequency shift with high admittance in the longitudinal mode. Operation measurements shift B2 as preload stiffness is fed back on the vibrator. The L1 mode is less affected as the motor is operated under no-load conditions. Admittance magnitudes are greatly reduced. Measurement results will be used for further resonator optimization.

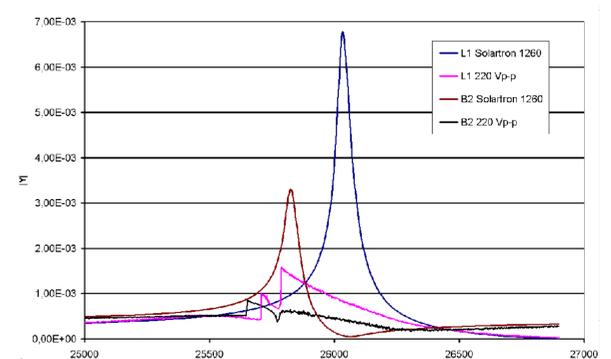


Fig. 7: Free vs. operation measurements

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