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Influence of overhanging tool length and vibrator material on electromechanical impedance and amplitude prediction in ultrasonic spindle vibrator

Key words: Ultrasonic spindle; Ultrasonic vibration assisted-milling (UVAM); 1-degree of freedom (DOF); Frequency; Amplitude; Milling

1-DOF Ultrasonic Resonance Transducer

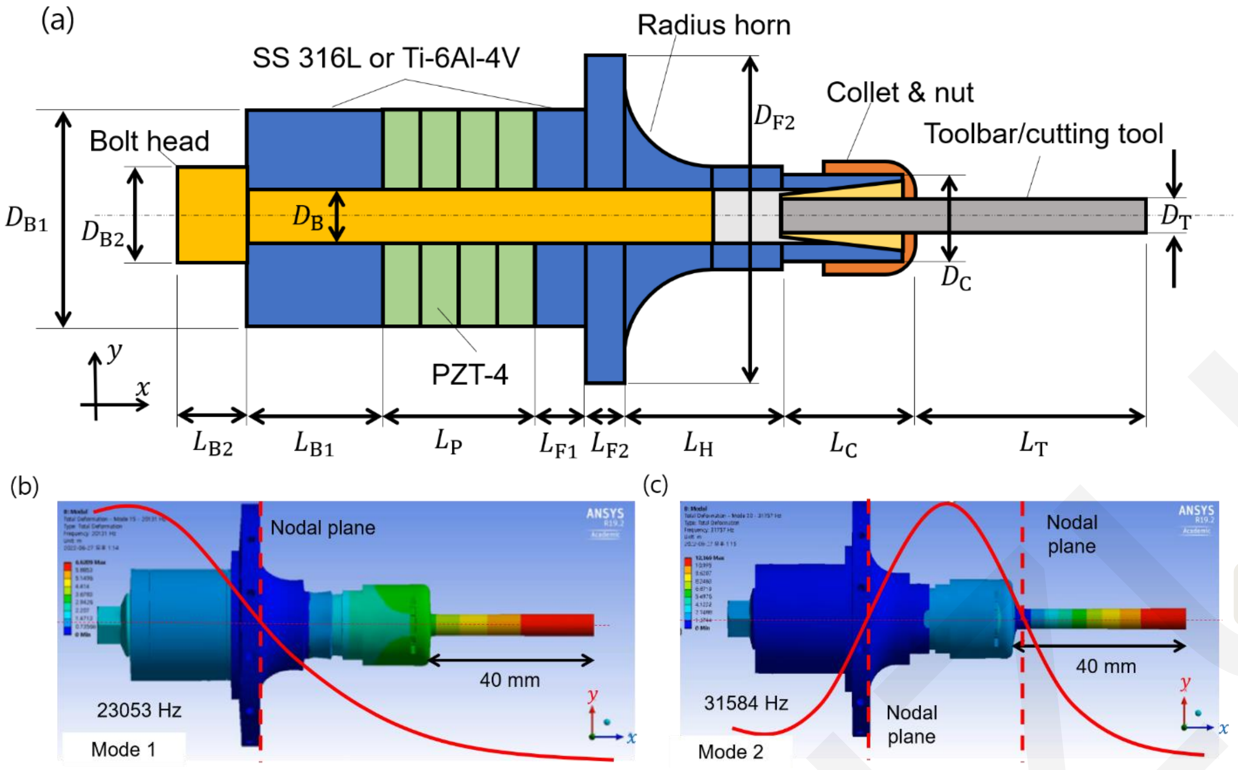

Fig. 1 Design of a 1-DOF ultrasonic resonance transducer made of SS 316L or Ti-6Al-4V: (a) schematic diagram; (b) 1st longitudinal mode; (c) 2nd longitudinal mode. *L*: length; *D*: diameter. Subscripts: B: screw bolt; P: piezoelectric ceramic actuator; T: toolbar; F: front mass; H: horn; C: collet & nut

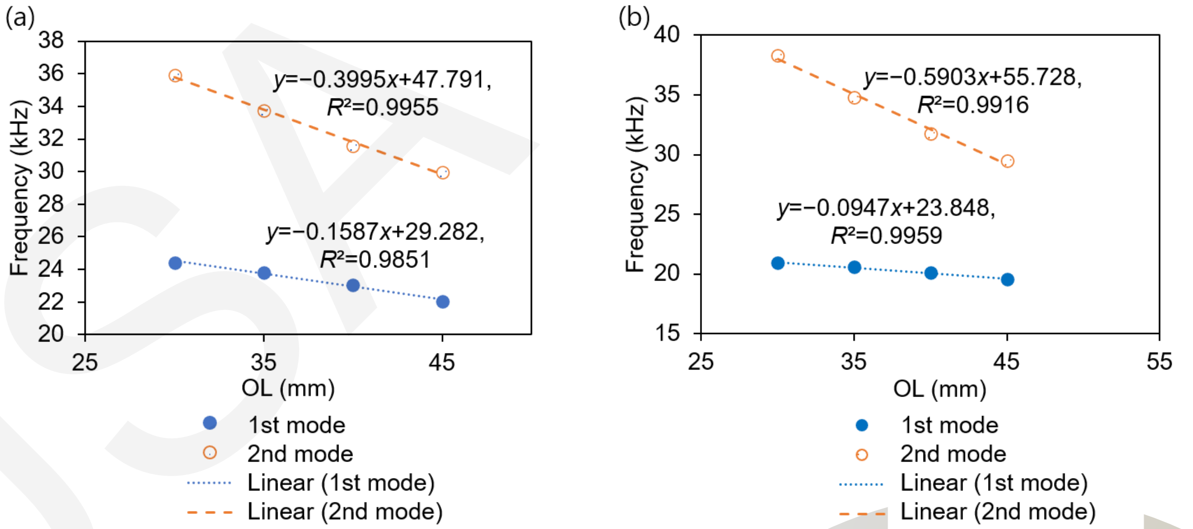

Fig. 2 Modal analysis frequency for the 1st and 2nd modes with SS 316L (a) and Ti-6Al-4V (b)

Fig. 1 shows a typical design for a 1-DOF ultrasonic resonance transducer. The toolbar behaves like an extension of the horn, which has a relationship to the resonance frequency.

Fig. 2 shows the outcomes of the modal simulation in ANSYS with a transducer made from different materials. The overhanging length (OL) affects the resonance frequency.

Electromechanical Impedance

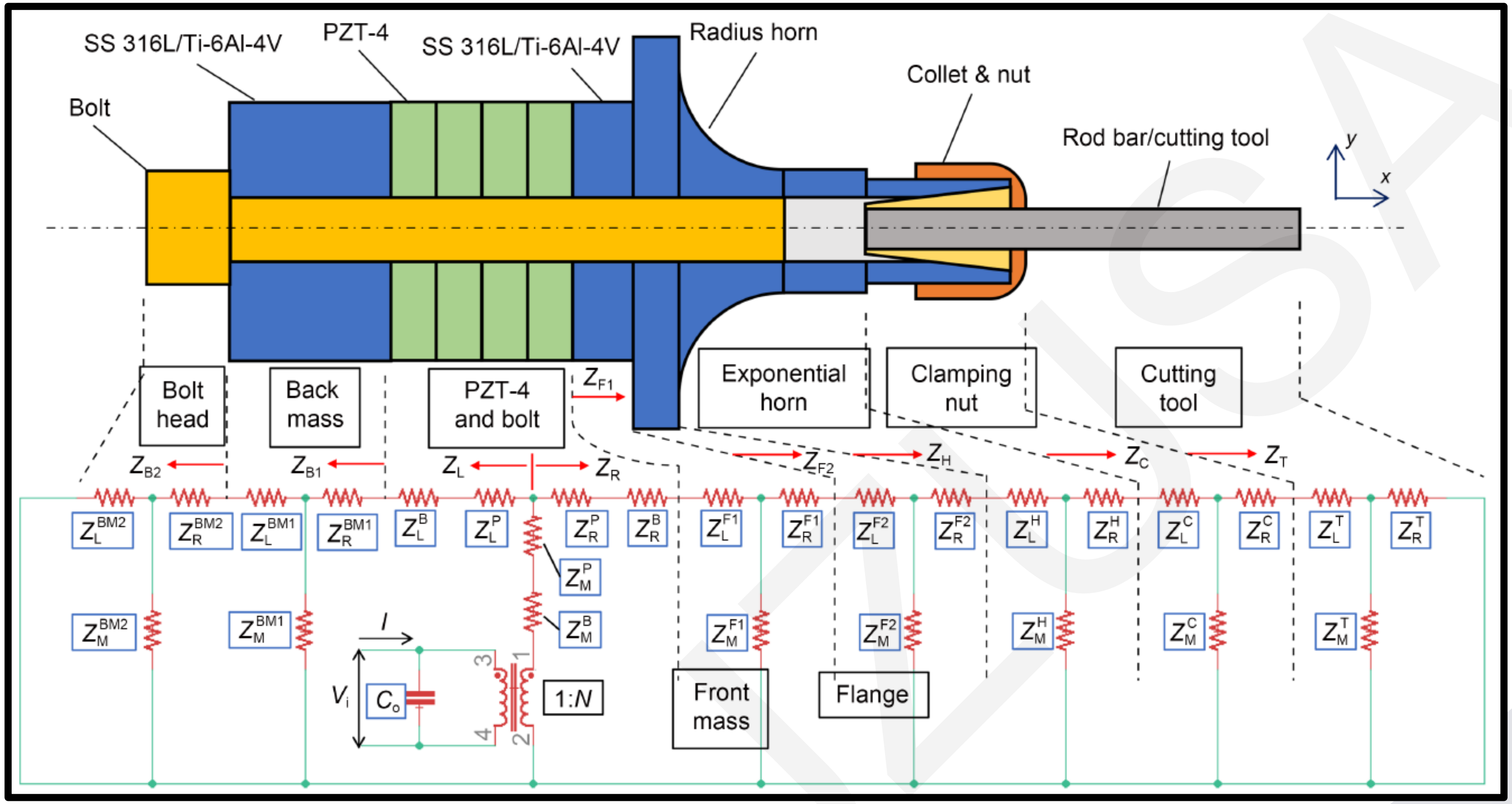

Fig. 5 Equivalent circuit model with T-type equivalent impedance structure

$$Z_e = \frac{Z_{C_o} \times N^2 \cdot Z_m}{Z_{C_o} + N^2 \cdot Z_m}$$

$$Z_{C_o} = \frac{1}{j\omega C_o}$$

Impedance Results

One can see from **Fig. 11** that the simulated FRF values for stainless steel correspond well with those in the experiment.

There are two peaks for each FRF impedance. The first resonance occurred because of OL.

As the OL increased, the first resonance moved to the left and the frequency became lower, which indicates that the OL increases the half acoustic wavelength.

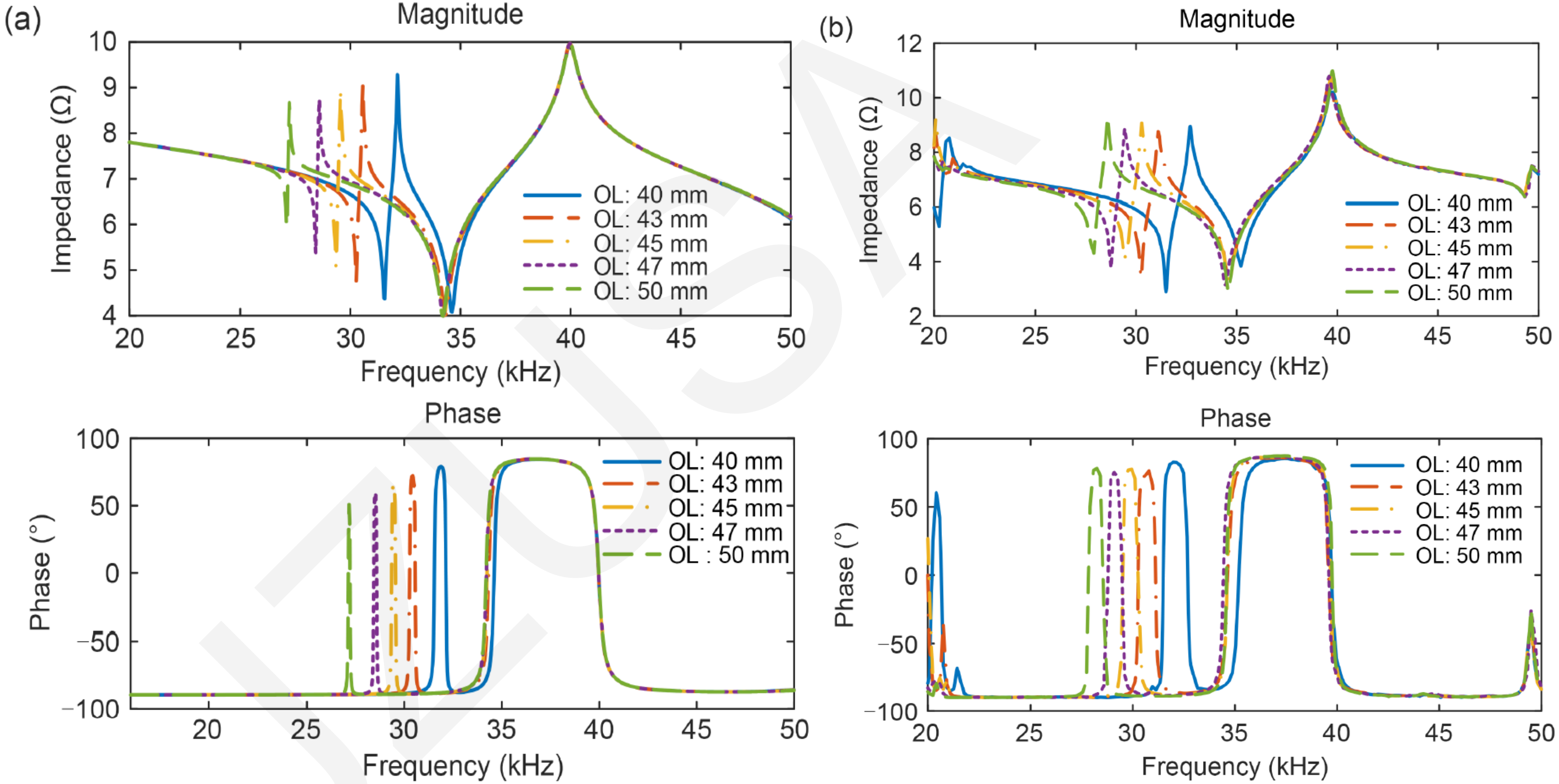

Fig. 11 Comparison between simulated and experimental FRF impedance of an ultrasonic transducer (stainless steel) (OL: 40 – 50 mm): (a) simulation; (b) experiment

Damping Ratio

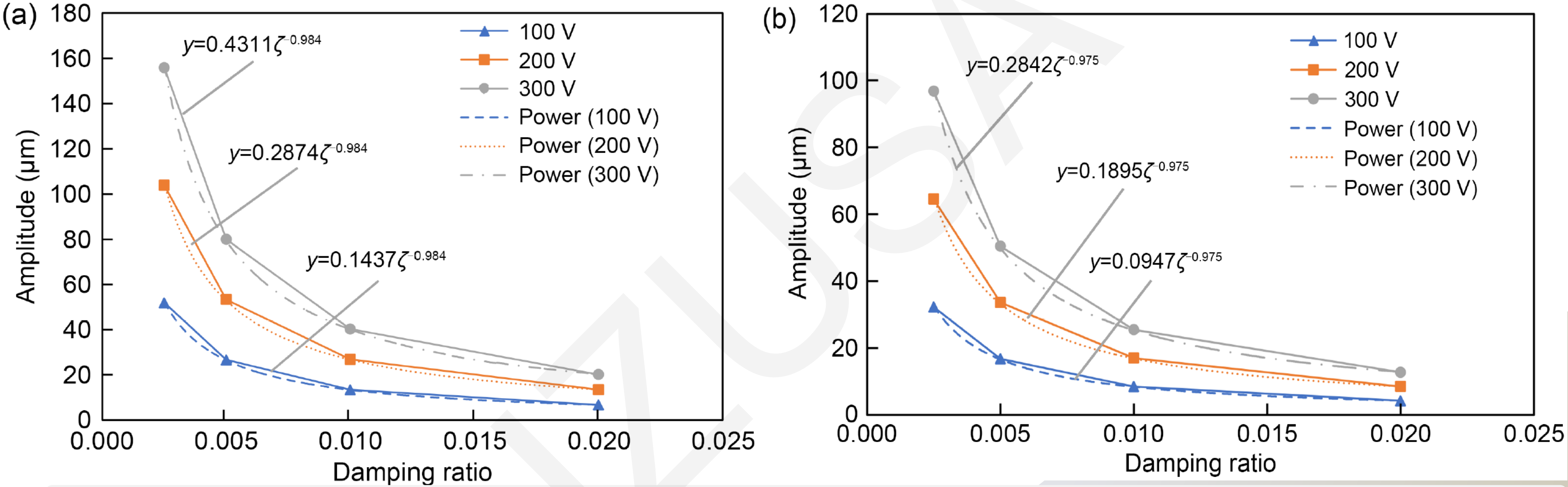

Fig. 15 Determination of the damping ratio versus amplitude of stainless steel (a) and titanium alloy (b)

Conclusions

We assessed an electromechanical impedance model and the effect of OL and different materials. We were able to draw the following conclusions:

- The electromechanical impedance simulation predicted resonance frequency with less than 3% error, and is thus useful for predicting the resonance ultrasonic frequency of ultrasonic transducers in the absence of a cutting load. In addition, the OL affects the natural oscillation frequency. When the OL increases, the resonance frequency decreases, indicating a larger acoustic half-wavelength.

- Harmonic simulation can be used to predict resonance amplitude. However, it is necessary to determine the damping ratio by calibration in order to estimate resonance amplitude precisely. The damping ratio of stainless steel was 0.015–0.020; the damping ratio of titanium alloy was 0.005–0.010. The error for amplitude prediction using harmonic simulation was less than 1.5%.