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# Nonlinear characterization of half and full wavelength power ultrasonic devices

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**Abstract**

It is well known that power ultrasonic devices whilst driven under elevated excitation levels exhibit nonlinear behaviors. If no attempt is made to understand and subsequently control these behaviors, these devices can exhibit poor performance or even suffer premature failure. This paper presents an experimental method for the dynamic characterization of a commercial ultrasonic transducer for bone cutting applications (Piezosurgery® Device) operated together with a variety of rod horns that are tuned to operate in a longitudinal mode of vibration. Near resonance responses, excited via a burst sine sweep method were used to identify nonlinear responses exhibited by the devices, while experimental modal analysis was performed to identify the modal parameters of the longitudinal modes of vibration of the assemblies between 0-80 kHz. This study tries to provide an understanding of the effects that geometry and material choices may have on the nonlinear behavior of a tuned device.


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*Keywords:* Power ultrasonics; EMA; Nonlinear behavior

## 1. Main text

It has been known, since the 1960s, that ultrasonic devices when driven under high vibrational levels near resonance exhibit nonlinear dynamic behaviors which can influence device performance (Albareda et al, Aurelle et al, Kumehara

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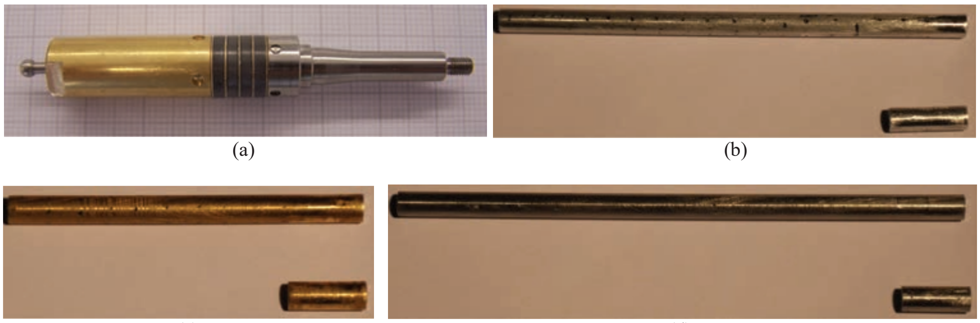
et al, Mathieson et al (2013), Mathieson et al (2015), Negishi, Umeda et al). These behaviors manifest in ultrasonic devices through shifts in resonant frequency, hysteresis loops, harmonic responses, and modal interactions. The source of these phenomena can be directly related to the presence of high stresses and strains within the power ultrasonic device whilst under high amplitude vibrational conditions.

The presence of nonlinear behavior has been extensively studied in materials used in the manufacture of ultrasonic devices. Notably, piezoceramic elements, which are employed in transducers to convert electrical energy into mechanical motion, possess vibrational thresholds above which exhibit nonlinear characteristics (Albareda et al, Aurelle et al, Negishi, Umeda et al). Furthermore, piezoceramic materials are prone to heating which also facilitates the manifestation of nonlinearities.

Although piezoceramics behave nonlinearly at relatively low excitation levels, this is not a unique source of nonlinear behavior in power ultrasonic devices. Tuned tool geometry and material of manufacture, along with connections or fastening points between components are also known sources of nonlinear behavior (Kumehara et al, Mathieson et al (2013), Mathieson et al (2015)). To differentiate between the mechanical sources of nonlinear behavior from those stemming from heating within the piezoceramic elements, an experimental technique has been employed which separates nonlinear behaviors originating from high stresses and strains from those due to elevated temperatures.

## 2. Transducer assemblies

Rod horns were tuned using finite element analysis (FEA) (Abaqus, Dassult Systèmes) to form half or full wavelength assemblies in conjunction with a commercial power ultrasonic transducer used in surgical procedures, Fig. 1(a). The half wavelength assemblies were tuned to vibrate in the first longitudinal mode of vibration, while the full wavelength assemblies were tuned to operate at the second longitudinal mode of vibration. To investigate the influence that material selection has on the behavior of the rod horns, three sets of horns were manufactured using different alloys, Fig. 1. The length of the rod horns and corresponding mechanical quality factor, $Q_m$, of the tuned assemblies (calculated using $\sqrt{2}$ peak method) can be seen in Table 1 (Stansfield (2002)).



(a) (b) (c) (d)

Fig. 1. (a) Commercial surgical transducer; (b) 6082 aluminum alloy rod horns; (c) brass rod horns; (d) 316 Stainless steel rod horns. The longer rod horn when assembled with the transducer forms a full wavelength power ultrasonic device. The shorter rod horns when assembled with the transducer form a half wavelength device.

Table 1. Rod horn length and $Q_m$ of transducer-rod horn assemblies.

| | Full wavelength assembly | | Half wavelength assembly | |
|---|---|---|---|---|
| | Length (mm) | $Q_m$ | Length (mm) | $Q_m$ |
| 6082 Aluminum alloy | 95 | 1228 | 16 | 492 |
| Brass | 60 | 955 | 13 | 316 |
| 316 Stainless steel | 110 | 337 | 13 | 311 |