Development of a Planar Stainless Steel Transducer and its Comparison to Titanium Ultrasonic Scalers for the Removal of Dental Biofilm and Calculus

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Introduction

Ultrasonic scalers are used by dental hygienists to remove dental biofilm and calculus from the teeth surface to reduce inflammatory conditions that can harm the periodontum. Langevin transducers are typically used for this purpose, consisting of a piezoelectric disc stack, a mechanical wave amplifier and an instrument tip. In previous work, a new generation of planar ultrasonic transducers was developed composed of two piezoelectric rectangular plates adhesively bonded to each side of a titanium horn. [1] The aim of this work was to develop a planar ultrasonic transducer made of stainless steel and to evaluate it in comparison with existing prototypes made of titanium. Key performance targets are a resonant frequency (fr) around 28 kHz and an achievable tip displacement amplitude of > 50 µm with less than 10 % out-of-plane motion.

Materials and Methods

Finite element method was used to evaluate the behavior of the chosen stainless steel 316L in terms of resonance properties. Following verification of the resonance behaviour and identification of a suitable design, nine transducers were manufactured using three different fabrication methods, including micro water jet cutting, vibratory finishing, and laser powder bed fusion. The manufactured transducers were evaluated for their manufacturing processes and tolerances as wells as for their performance by means of electromechanical characterization. This involved microscopy, measurement of impedance amplitude and phase as well as in-plane and out-of-plane mechanical deflection analysis using laser Doppler vibrometry (LDV). The final prototypes were installed in a housing for *in vitro* testing by the dental clinics of Bern (ZMK) to evaluate clinical performance against commercial and titanium-based scalers.

Figure 1: Three-dimensional FEM simulation with COMSOL Multiphysics 6.0 to identify longitudinal eigenmodes.

Results

The simulation indicated that the change from titanium to stainless steel does not have a major impact on the resonance behaviour, the f_r decreases by about 340 Hz, allowing the same design to be adopted for the new steel prototypes (Figure 1). Prototypes of all manufacturing processes have been

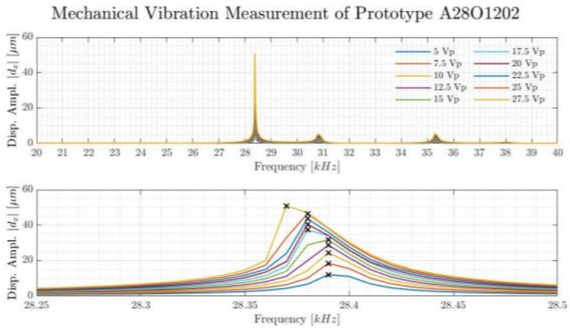

Figure 2 in-plane LDV measurement of the best performing stainless steel prototype at different voltage levels.

fabricated reproducibly and are functional. They have a resonant frequency of 28.37 ± 0.03 30 kHz and achieved displacement amplitudes of up to 51 µm at a power of 1.6 W (27.5 Vp) (Figure 2).

Discussion

The simulation provides a good estimate of the transducer performance at low power < 2 W. At higher powers, non-linear damping effects have a strong impact, which would require further optimisation of the FE model. The performance objectives for free-air operation have been achieved. In comparison to the titanium-based transducers the performance is slightly lower. However, for a valid comparison, the method of tip finishing should be improved, and its competitiveness still needs to be evaluated under real conditions.

References

[1] M. Hofmann et al. TOOL TIP, TOOL FOR DENTAL TREATMENT HAVING SUCH A TOOL TIP AND METHOD FOR OPERATING SUCH A TOOL. EP3970654A1; WO2022/058441A1. 2022.

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