Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 87 (2016) 35 – 41

Physics Procedia

44th Annual Symposium of the Ultrasonic Industry Association, UIA 44th Symposium, 20-22 April 2015, Washington, DC, USA and of the 45th Annual Symposium of the Ultrasonic Industry Association, UIA 45th Symposium, 4-6 April 2016, Seattle, WA, USA

Optimisation of a cymbal transducer for its use in a high-power ultrasonic cutting device for bone surgery

Fernando Bejarano, Andrew Feeney, Margaret Lucas*

School of Engineering, University of Glasgow, Glasgow G12 8QQ, UK

Abstract

The class V cymbal is a flextensional transducer commonly used in low-power ultrasonic applications. The resonance frequency of the transducer can be tailored by the choice of end-cap and driver materials, and the dimensions of the end-caps. The cymbal transducer has one significant limitation which restricts the operational vibration amplitude of the device. This is the limit imposed by the mechanical strength of the bonding agent between the metal end-cap and the piezoceramic driver. Therefore, when there is an increase in the input power or displacement, the stresses in the bonding layer can lead to debonding, thereby rendering the cymbal transducer ineffective for high-power ultrasonic applications. In this paper, several experimental analyses have been performed, complemented by the use of Abaqus/CAE finite element analysis, in order to develop a high-power ultrasonic cutting device for bone surgery using a new configuration of cymbal transducer, which is optimised for operation at high displacement and high input power. This new transducer uses a combination of a piezoceramic disc with a metal ring as the driver, thereby improving the mechanical coupling with the metal end-cap.

Peer-review under responsibility of the Ultrasonic Industry Association.

Keywords: Cymbal transducer; transducer design; high-power; ultrasonic bone surgery

1. Introduction

Although the first attempts to introduce the ultrasonic technology in bone cutting procedures were made by Catuna in 1952, with a drilling device for dentistry (Mathieson (2012)), it was not until 2001 when the first commercial device

* Corresponding author. Tel.: +44 (0)141-330-4323.
E-mail address: margaret.lucas@glasgow.ac.uk

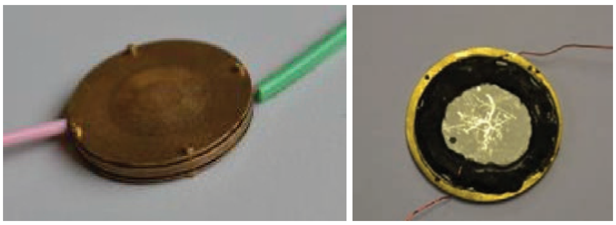
Peer-review under responsibility of the Ultrasonic Industry Association.
doi:10.1016/j.phpro.2016.12.007

designed for bone cutting applications was available. The Piezosurgery® device, which is the result of a collaboration between a maxillofacial surgeon, Vercellotti, and the Italian company Mectron S.p.A (Vercellotti (2004)), is based on a Langevin transducer, and is optimised for driving cutting inserts for a range of surgical procedures. Many studies have been conducted on the performance of the Piezosurgery® device, in order to understand how to improve the mechanical and clinical efficacy of the system.

The cymbal transducer was developed at the Materials Research Laboratory, Penn State University, and patented by Newnham and Dogan in 1998 (Dogan et al. (1997)). The transducer is a class V flextensional-type, consisting of an electroactive driver in the form of a piezoelectric ceramic ring or disc, poled in the thickness direction, sandwiched between two shallow-shell metal end-caps. The end-caps serve as mechanical transformers for conversion and amplification of the relatively small radial displacement of the piezoelectric ceramic into a much larger axial flexural motion normal to the surface of the end-caps. Each end-cap possesses a shallow cavity on the inner surface, the dimensions of which significantly influence the resonance frequency of the transducer. There is significant opportunity for a new generation of miniaturised bone cutting devices to be developed, based on modifications to the cymbal transducer configuration.

In the traditional cymbal transducer design, the piezoelectric ceramic disc and the metal end-caps are bonded together using a high-strength epoxy. Therefore, the conversion of the radial displacement of the piezoelectric ceramic (poled in thickness direction) to the flexural-rotational displacement of the metal end-caps depends exclusively on the mechanical coupling of this bonding agent. The cymbal transducer has been widely adopted for low-power applications, but the mechanical coupling was found to be a critical limitation when the cymbal was driven at high voltages or high displacements (Ochoa et al. (2006); Ochoa et al. (2007)).

In 2010, Lin developed a modified design of the cymbal transducer in which a metal ring was used to enclose the piezoceramic driver using a thermal expansion/contraction method (Lin (2010)). The end-cap, with a larger flange in order to accommodate the metal ring, was then affixed directly to the metal ring through a bolted interface, thereby improving the mechanical coupling by eliminating the epoxy resin bond layers. Since the cavity dimensions can be controlled, this new cymbal transducer could be designed to exhibit approximately the same resonance frequency as a cymbal transducer of the traditional design, but with the capacity for operation at higher displacement amplitudes before failure. The new cymbal transducer is shown in Fig. 1(a). For the purposes of this study, the mechanical coupling was adapted from that used by Lin. Epoxy resin was used to fill the gap between the outer edge of the piezoceramic disc and the inner surface of the metal ring. This is shown in Fig. 1(b).



(a) (b)

Fig. 1. (a) The new cymbal transducer; (b) the coupling between the PZT disc and metal ring.

In this study, a prototype device for ultrasonic bone cutting surgery is proposed, adapted from the cymbal transducer design shown in Fig. 1. The adapted device comprises only one end-cap with a supporting back-shell in which the piezoceramic driver is fixed in place with insulating epoxy resin. The metal end-cap is attached directly to the back-shell with a bolted connection. The design of the whole transducer is optimised to transfer the radial movement of the piezoelectric disc directly to the metal end-cap, so that in resonance the device exhibits an axial vibration motion. Experimental data is supported in part by numerical simulations using Abaqus/CAE finite element analysis (FEA) software.