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A miniaturized class IV flextensional ultrasonic transducer

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Abstract

The class V transducer has found popularity in a diverse range of applications such as surgical and underwater projection systems, where high vibration amplitude for relatively low piezoceramic volume is generated. The class IV transducer offers the potential to attain even higher performance per volume than the class V. In this research, a miniaturized class IV power ultrasonic flextensional transducer is proposed. Simulations were performed using PZFlex finite element analysis, and electrical impedance analysis and experimental modal analysis were conducted for validation, where a high correlation between simulation and experiment has been demonstrated.

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Keywords: Class IV transducer; flextensional; power ultrasonic; experimental modal analysis; finite element analysis

1. Introduction

The class IV transducer is a form of flextensional transducer which has found success in many low-frequency underwater applications (Chen and Yu, 2013). Although notable early research on the class IV transducer was conducted in the 1960s, for example using a piezoceramic driver by Toulis, the first recorded occurrence of a class IV flextensional transducer was in a patent filed in 1936 by Hayes (Rolt, 1990). A class IV flextensional transducer consists of a magnetostrictive or piezoelectric driving stack, typically in the form of a bar, which vibrates longitudinally to drive an oval shell configuration. The vibration of the driving element causes a combined flexural

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and extensional motion of the shells to produce high amplitude motion. Materials commonly used to fabricate the shells for underwater applications include steel, high-strength aluminium and glass reinforced plastic (GRP), while materials such as PZT-4, PZT-8, and PMN are popular piezoelectric driver materials.

The cymbal transducer, which was successfully miniaturized and adapted from the class V configuration by Newnham et al. (Zhang et al., 1999), has recently been used to create a prototype for orthopedic surgery (Bejarano et al., 2014). Despite the success of this device, it is anticipated that the achievable output amplitude per unit volume of piezoceramic will be greater by using a class IV configuration. In this investigation, the traditional class IV transducer design has been modified to enable future development of miniaturized power ultrasonic devices. The oval shells have been replaced with end-caps which include flanges to affix directly to the piezoceramic bar using an epoxy resin. A schematic of the traditional class IV flextensional transducer, and the modified design, are shown in Fig. 1.

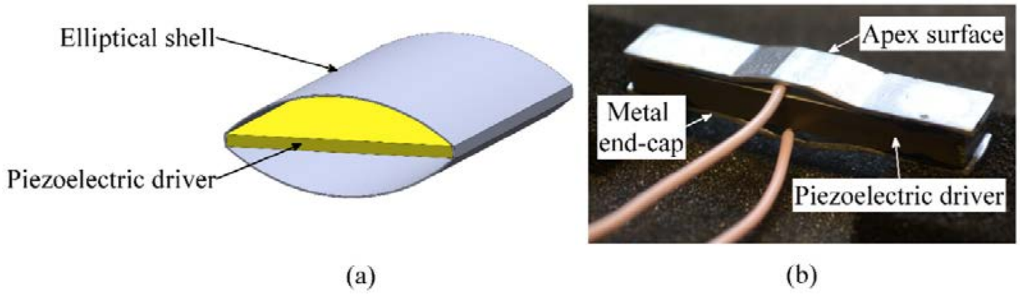

Fig. 1. (a) Schematic of the traditional class IV flextensional transducer; (b) the modified and miniaturized class IV flextensional transducer.

The apex surface of each end-cap has been included to provide a mechanism for the attachment of an end-effector, such as a cutting blade, as shown in Fig. 1(b). To ensure device stability when an end-effector is connected to the transducer during operation, a high level of amplitude uniformity on the end-cap apex is required to minimize the likelihood of nonlinear and autoparametric responses. Furthermore, a robust mechanical coupling mechanism is also required to join the end-cap to the piezoceramic element in order for the device to withstand high stresses induced by elevated operational amplitudes. Recent investigations into adapting flextensional transducers for high-power applications have been conducted, such as the design and fabrication of devices based on the class V cymbal transducer (Bejarano et al., 2014, Lin, 2010), which eliminated epoxy resin bond layers to improve mechanical coupling, and also the modification of the class IV transducer by employing a monolithic configuration (Hladky-Hennion et al., 2008). However, the performance of the monolithic form of the class IV transducer has not yet been fully evaluated for its suitability to high-power applications.

This research outlines the design and fabrication of a miniaturized class IV type flextensional transducer with modified end-caps for power ultrasonic applications. The finite element analysis (FEA) software, PZFlex, is used to design the transducer before the experimental validation of the model is conducted using a vibration characterization process, comprising electrical impedance measurements (Agilent 4294A impedance/gain phase analyzer) and experimental modal analysis (EMA) using 3-D laser Doppler vibrometry (Polytec CLV).

2. Finite element analysis

A set of dimensions for a high performance class IV type transducer were calculated from an iterative simulation process using the FEA software PZFlex. A Navy Type I piezoceramic plate was chosen as the driving element of the transducer (Ferroperm Hard PZ26, Meggitt A/S), while stainless steel 316 was selected as the transducer end-cap material. A skewed structure grid was used to accurately represent the end-cap structure, while shell elements minimized the time step of the explicit solver, increasing computation efficiency. In PZFlex software, the damping is usually applied in the material model definitions and is dependent on frequency. The PZ26 plate was modelled as a continuum material, where the damping was applied as a Q of 200. The model of the transducer used for the simulations in PZFlex is shown in Fig. 2.