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# Dynamics characterisation of cymbal transducers for power ultrasonics applications

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**Abstract**

A class V cymbal flextensional transducer is composed of a piezoceramic disc sandwiched between two cymbal-shaped shell end-caps. Depending on the type of piezoceramic, there exists a maximum voltage that can be reached without depolarisation, but also, at higher voltage levels, amplitude saturation can occur. In addition, there is a restriction imposed by the mechanical strength of the bonding agent. The effects of input voltage level on the vibration response of two cymbal transducers are studied. The first cymbal transducer has a standard configuration of end-caps bonded to a piezoceramic disc, whereas the second cymbal transducer is a modified design which includes a metal ring to improve the mechanical coupling with the end-caps, to enable the transducer to operate at higher voltages, thereby generating higher displacement amplitudes. This would allow the transducer to be suitable for power ultrasonics applications. Furthermore, the input voltages to each transducer are increased incrementally to determine the linearity in the dynamic responses. Through a combination of numerical modelling and experiments, it is shown how the improved mechanical coupling in the modified cymbal transducer allows higher vibration amplitudes to be reached.


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*Keywords:* Cymbal transducer; linearity; high-power; ultrasonics

## 1. Introduction

Flextensional transducers have been in existence for a number of years, primarily being used in underwater and sonar applications since the 1920s (Zhang et al., (1999)). Cymbal transducers are a variation of the flextensional

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design, and were developed in the early 1990s by Newnham et al. at the Penn State University Materials Research Laboratory (Zhang et al. (2000)). It is only recently that their capabilities in alternative applications and at high amplitudes have being investigated. Presently, the incorporation of cymbal transducers into high-power ultrasonic technology is underdeveloped, primarily because the bonding agent in the configuration imposes voltage or displacement limits at which the cymbal transducer can be driven. This is one of the issues which this paper aims to address.

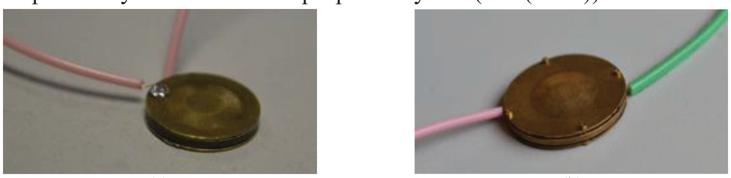
The two most critical aspects of the cymbal design that affect the vibration performance of a cymbal transducer are the cavity dimensions and the thickness of the end-caps (Sun et al. (2005)). The end-cap of the transducer acts as a mechanical transformer, to convert high impedance, low displacement radial motion into low impedance, large axial-flexural motion (Zhang et al., (1999)). In recent years, there has been a significant research effort to expand the range of applications in which cymbal transducers can be used, as well as developing evolutions of the designs for application in different environmental conditions (Newnham et al. (2000)). For example, cymbal transducers have found prominence in energy harvesting (Yuan et al. (2010)). However, the number of applications in which cymbal transducers are operating in commercial devices, despite being of a wide variety, is still limited. Since epoxy is commonly used as the bonding agent, there exists an operating limit of the transducer, where debonding will occur if the input power is too high. Also, because radial motion is converted into large-amplitude flexural motion, robust mechanical coupling should exist between all components (Lin (2010)). The dimensions of the end-caps affect the frequency of the cymbal transducer (Lin (2010)), and improved designs that aim to enhance the mechanical coupling can result in many complex modes being present in the vibration response.

In this paper, two cymbal transducer designs are studied. The first is of the standard design developed by Newnham et al., and the other is based on a design proposed by Lin in 2010 (Lin (2010)), which incorporates a metal ring with the aim of improving mechanical coupling in the transducer, by removing the problems associated with debonding in the epoxy layer. It is evident from the literature that new interest in cymbal transducers is emerging, and that as yet there has not been a fully comprehensive study into the dynamic characteristics of this type of flextensional transducer when driven at higher voltages, particularly with respect to an analysis of linear dynamic response. Additionally, the investigation of the operational limit of these transducers relative to increasing input voltage has not received significant attention. The results of the experimental studies are presented with support from finite element analysis (FEA), which was conducted using Abaqus/CAE Version 6.10 software.

## 2. Cymbal transducer fabrication

### 2.1. Cymbal end-cap manufacture

The fully assembled standard and modified designs used in the experiments are shown in Fig. 1. The modified design is based on the improved cymbal transducer proposed by Lin (Lin (2010)).



(a) (b)

Fig. 1. (a) The standard cymbal transducer; (b) the modified cymbal transducer.

Each cymbal end-cap was cut from brass sheet, and hard PZT (PZT-402) discs of 12.7mm diameter, 1mm thickness were used as the driving element in the assembly. Table 1 shows the dimensions of the cymbal transducer components. The material properties, which were also used in the FEA, are shown in Table 2. The modified cymbal transducer incorporates a brass ring around the PZT disc which improves the mechanical coupling and decreases the stress on the epoxy layer, thereby allowing operation at higher amplitudes. For the modified transducer, the total diameter of the brass end-caps had to be increased from 12.7mm, required for the standard configuration, to 16.7mm, to allow the