Nitinol Cymbal Transducers for Power Ultrasonics Applications

Andrew Feeney[1] and Margaret Lucas[1]

[1]School of Engineering, University of Glasgow, Glasgow, G12 8QQ, UK

[a]a.feeney.1@research.gla.ac.uk

Abstract. The effects of shape memory alloy phenomena such as superelasticity and thermal phase change on the dynamic response of a cymbal transducer incorporating two Nitinol end-caps has not been studied into detail. The experimental results, using both vibration response and electrical impedance measurements, demonstrate that the use of Nitinol as the end-cap material for a cymbal transducer can impose significant effects on the vibration response. The understanding of the effect Nitinol has on the vibration response of a cymbal transducer provides future opportunities to design a power ultrasonic cymbal transducer that can operate with two different and selectable vibration behaviours, which is particularly appealing in a range of applications, including ultrasonic cutting devices that are required to penetrate more than one material.

Introduction

A cymbal transducer is composed of a piezoceramic driver disc sandwiched between two cymbal-shaped shell end-caps, converting high impedance, low radial displacement of the piezoceramic into low impedance, large axial displacement of the end-cap [1]. It is only very recently that their suitability for high amplitude and high power ultrasonics applications has been studied. Shape memory alloys (SMAs) are a unique class of metals which exhibit two interesting and unique properties, one of which is the shape memory effect (SME), which involves a thermally-induced phase change between a cubic austenite phase and a monoclinic martensite phase. The other is called the superelastic effect, which occurs isothermally when the material is stressed at a temperature above its final austenitic transformation temperature [2]. The material undergoes a change in microstructure which reorients the austenite phase to the martensite phase. One type of SMA that has received much attention in recent years is Ni-Ti, or ‘Nitinol’, and this study evaluates the effect of Nitinol end-caps on the vibration response of a cymbal transducer.

Transducer Manufacture

The custom Nitinol end-caps (Johnson Matthey Noble Metals) were manufactured to be in an oxide-free superelastic condition. The binary alloy was composed of 55.99wt% Ni with a balance of Ti. The transformation temperatures were determined using Differential Scanning Calorimetry (DSC), which showed that the material existed in its austenite phase around room temperature. The end-cap of the cymbal transducer has a thickness of 0.25mm, total diameter of 12.7mm, an apex cavity diameter of 4.5mm, base cavity diameter of 9.0mm and a maximum cavity depth of 0.3mm. The piezoceramic disc has a diameter of 12.7mm and a thickness of 1.0mm. Hard, Navy Type I, PZT discs (Piezo Kinetics) constituted the piezoceramic driver material. A layer of insulating epoxy resin (Eccobond, Emerson & Cuming) was applied to the flange of each end-cap before careful assembly, and left to cure at room temperature for 24 hours. Fig. 1 shows a fully-assembled Nitinol cymbal transducer.

Fig. 1. A fully-assembled Nitinol cymbal transducer.

Impedance Analysis

The device was characterised in two different temperature conditions using an impedance analyser (Agilent 42941A) to show how the Young’s Modulus of the material can significantly change, and the results are shown in Fig. 2. The Nitinol was characterised at room temperature before being forced away from its austenitic state by measuring the impedance response at a temperature of -10°C. Each trough in the results represents the axial mode of vibration for a particular end-cap. The significant change in the resonance frequency is evidence of a change in Young’s Modulus resulting from a shift between the intermediate R-Phase and the austenite phase. There can be small disparities in the response of the two end-caps, creating a double-peak, which is a common occurrence, because the bond layer can be uneven and there can be slight asymmetries in the end-caps or in the transducer.

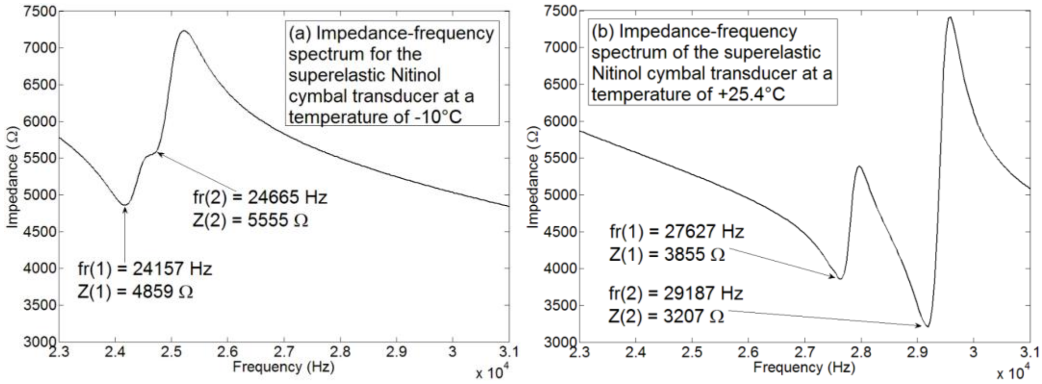

Fig. 2. Impedance-frequency spectra for different material states.

Vibration Response Analysis

A Nitinol alloy can be considered to be superelastic in the range up to approximately 50°C above the Austenite Finish (A_f) temperature [3]. A type K thermocouple was located in close proximity to the cymbal transducer to ensure that the environment was being maintained in the temperature range appropriate for superelasticity, of around 23°C and above. A 1D laser vibrometer (Polytec CLV) was used to measure the output vibration displacement response of the device, the results of which are shown in Fig. 3.

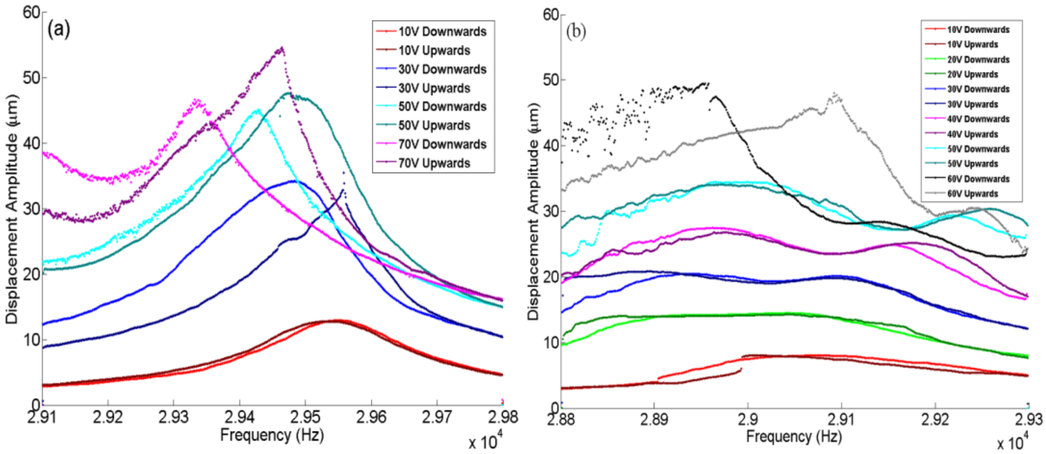

Fig. 3. Vibration response results for the (a) original superelastic Nitinol cymbal transducer, (b) transducer with suspected bond defect.

Whilst Figure 3(a) shows the vibration response of the superelastic Nitinol cymbal transducer, Figure 3(b) shows the results of the experiment on the same transducer tested over a similar voltage range, where a failure was suspected in the bond layer. The frequency responses measured at the higher voltage levels in the excitation range, such as 50V and 70V, appear to be more affected by localised superelastic effects. This would be expected, as a higher voltage input excites higher displacement amplitude, hence resulting in higher stress on more of the end-cap.

Conclusions

These results show strong evidence that the resonant response of a cymbal transducer with superelastic Nitinol end-caps exhibits contributions from both martensite and austenite phases. As the input excitation voltage is increased, the displacement amplitude increases, resulting in higher stress on a larger proportion of each end-cap and consequently a larger shift in the resonant frequency of the device.

References

[1] J. Zhang, A-C. Hladky-Hennion, W.J. Hughes and R.E. Newnham: *Modeling and Underwater Characterization of Cymbal Transducers and Arrays*, IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, Vol. 48, No.2 (2001), p. 560-568.

[2] J.A. Shaw, C.B. Churchill and M.A. Iadicola: *Tips and Tricks for Characterizing Shape Memory Alloy Wire: Part 1 – Differential Scanning Calorimetry and Basic Phenomena*, Experimental Techniques 32(5) (2008), p. 55-62.

[3] D. Stöckel: *Nitinol – A Material with Unusual Properties*, Endovascular Update, Issue 1 (1998), p. 1-8.