Fabrication and Dynamic Characterisation of a Nitinol Langevin Transducer

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Abstract. The Langevin transducer is a common configuration of device in power ultrasonics applications, across medical and industrial ultrasonics. It has been widespread in surgery and dentistry, and also for industrial applications including welding. The configuration relies on tuning to a single resonance frequency, however there is growing demand for resonance tuneability. For example, in surgery it is common to replace cutting tips for operation on different target materials. By utilising a shape memory material instead, whose elastic properties can be shifted with temperature or stress, there is the opportunity to remove this need for replacement. In this study, a Langevin transducer is fabricated and characterised, where the end-masses are manufactured from the shape memory alloy Nitinol. The prototype is characterised, showing resonance tuneability across a relatively small temperature difference of 30°C, showing potential for practical application.

Introduction

Langevin transducers are composed of two end-masses, front and back, and a piezoelectric stack consisting of rings of piezoelectric material electrically connected to electrodes, where the structure is preloaded with a bolt. It is employed in several power ultrasonic applications, including ultrasonic motors, scalpels, and drills. The principal innovation in this study is the incorporation of Nitinol into the structure, which is a temperature dependent shape memory, or smart, material, and is a binary alloy of nickel and titanium. Nitinol undergoes a microstructural phase transformation between martensite and austenite in response to temperature, which shifts the elastic moduli. These can be in the order of 40 GPa for martensite and 90 GPa for austenite. A shift in modulus for a device incorporating Nitinol would hence change the resonance frequencies. Such adaptive ultrasonic devices are already possible, for example the cymbal transducer whose modal frequencies can be tuned over thousands of Hz [1]. However, the work hardening of Nitinol makes it difficult machine by conventional methods. There can also be high tool wear and the formation of burrs [2]. Here, electrical discharge machining is proposed for the manufacture of a prototype Nitinol Langevin transducer, before dynamic characterisation is performed to capture the first longitudinal mode shape and resonance frequencies.

Transducer Manufacture

Shape memory Nitinol cylinders were procured from Kellogg's Research Labs, with an austenite finish temperature of 45°C. This means that the phase microstructure in the material will be fully austenitic above 45°C. For the purposes of measurement, it was important to define an austenite finish temperature sufficiently above room temperature, to ensure stable dynamic measurement of the transducer. The cylinders were used to fabricate the front and back masses of the Langevin transducer prototype, each with a length of 10 mm and a diameter of 25 mm. A thread was machined into the front mass and a hole was created in the back mass, to accommodate the central preloading bolt of the transducer. This was undertaken via electrical discharge machining (AD35L, Sodick Europe Ltd.), as shown in Fig. 1.

Fig. 1: The machining process applied to the Nitinol cylinders to create the prototype end-masses.

Once the front and back masses were fabricated, the prototype Langevin transducer was completed using a pair of hard lead zirconate titanate (PZT) ceramic rings (PZ26, Meggitt), each with an outer diameter of 20mm, alongside two copper electrodes to constitute the PZT stack. The front and back masses and the PZT stack were bolted together with an M8 stainless steel bolt under 11 Nm of preloading. The manufactured prototype transducer is shown in Fig. 2.

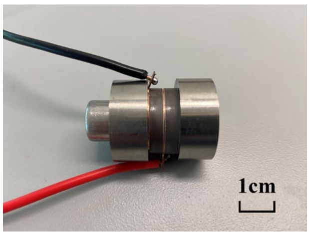

Fig. 2: The prototype Nitinol Langevin transducer.

Vibration Analysis

Once fabrication was complete, the transducer was allowed to age for one week, to relax the stresses induced by the preloading process and for stable dynamics to be achieved. The prototype was then characterised using 3-D scanning laser Doppler vibrometry (MSA-100-3D, Polytec) to measure the vibration mode. As shown in Fig. 3, the first longitudinal mode shape at 44.14 kHz was found at room temperature, for an 8 V excitation.

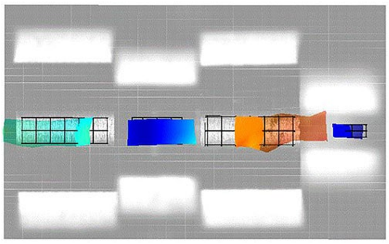

Fig. 3: The first longitudinal mode of the transducer, as measured via laser Doppler vibrometry.

The resonant frequency of the longitudinal mode shape was used as the reference for electrical impedance measurement (Agilent 4294A, Keysight Technologies), to monitor resonant frequency shift as a function of temperature. Impedance spectra were collected as functions of temperature, where the transducer was heated by a commercial dehydrator and real-time temperatures were measured by a thermocouple (RS PRO 1384, RS Component). The results are shown in Fig. 4, where the series resonances can be identified.

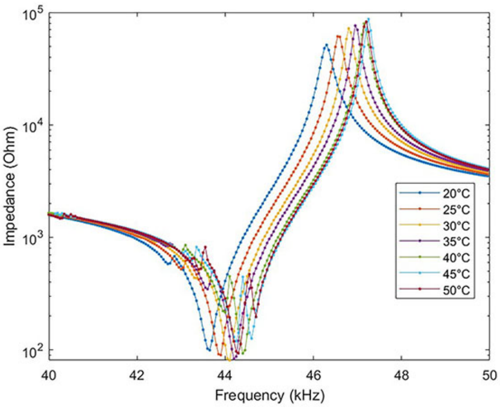

Fig. 4: Electrical impedance spectra of the prototype as functions of temperature.

The results demonstrate that as temperature is raised above the final austenitic transformation temperature, the Nitinol continues its transformation to austenite, thus the elastic modulus of the end-masses increase, raising the resonant frequency, here by 650 Hz from 20-50°C.

Conclusion

In this study, the manufacture and characterisation of a Nitinol Langevin transducer has been demonstrated. Electrical discharge machining has been shown to be a practical method of fabrication, and measured electrical impedance spectra demonstrate that the transducer has desirable frequency tuning ability over a relatively small temperature range. Future work will focus on widening the magnitude of frequency shift and on practical medical and industrial applications.

References

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