FABRICATION AND MECHANICAL CHARACTERIZATION OF RING-SHAPED LTCC/HTCC FINGER FORCE SENSORS USED FOR PERFORMANCE STUDIES IN CLARINET PLAYING

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When performing on a clarinet the finger tips of certain fingers act like air valves to change the effective length of the clarinet's bore and thus the tone pitch. To tightly close a pipe's hole, a distinct finger force is required. If the hole is already closed and even more force is applied the tone of the clarinet will not change. However, the fast movement of the fingers may be restricted due to too much tension of the fingers. In order to investigate this behavior a special force sensor design is required, providing the same haptics as an ordinary pipe. A unique combination of LTCC and HTCC (low and high temperature co-fired ceramics) technology has been chosen for this purpose, allowing the manufacturing of both the sensing elements and the ring-shaped package. As shown in Fig. 1 the force sensor together with a spacer ring replaces a part of the original pipe.

The schematic of the force sensor based on the piezoresistive principle is given in Fig. 2. Three identical sensor branches n=1,2,3 were embedded into the sensor, placed at 0°, 120°, and 240° in order to determine the finger's position on the ring.

The package is composed of a 9-layer laminate of LTCC tapes (Heraeus CT708 tape material). The four topmost layers incorporate the conductive paths, vias and pads (Heraeus TC7305-A/7304-A silver system) for the piezoresistive elements Rs,n, Rc,n and electronic devices. The five bottommost layers are used to form recesses for the electronic components to provide a plain bottom surface. After sintering the package (peak temperature 850°C, dwell time 28 mins) the electronic devices (R1, R2, three Analog Devices AD8235 instrumentation amplifiers Un with gain setting resistors RG,n (Gain=35) and decoupling capacitors C1, C2) have been soldered using vapor phase soldering (see Fig. 3).

As substrate for the piezoresistive elements Rs,n and Rc,n a partially stabilized zirconia HTCC tape (ESL 42013-A) has been chosen. Compared to other LTCC/HTCC materials this tape shows a high mean flexural strength around 613 MPa. Three layers of 125 µm thick ESL 42013-A have been laminated (75°C/11 MPa for 3 mins) to be suitable for maximum forces of at least 5 N. After sintering the substrate (peak temperature 1450°C, dwell time 7 hs) piezoresistive and conductive thick-film layers (ESL 3414A and Heraeus TC7304-A) have been applied by screen-printing and post-fired (LTCC sintering profile). Pairs of resistors with close-by resistance were chosen for Rs,n and Rc,n. Whereas Rs,n acts as active sensing element, Rc,n has been sand blaster trimmed (ComCo Systems TR1800) to the value of Rs,n ± 0.1 % to act as passive bridge element.

The active and passive piezoresistive elements were mounted on top of the bottom section using conductive epoxy adhesive (Polytey EC 201). On top of each active piezoresistive element a glass spacer (0.7 mm SiLi Type-P soda lime glass beads) was fixed using standard epoxy adhesive to achieve a defined position where the finger force will be applied (see Fig. 4). Ring-shaped POM spacers were finally attached on the glass spacers to preserve the haptics of the original pipe. Fig. 5 shows the upper joint of a clarinet equipped with three ring-shaped force sensors.

The mechanical characterization of the ring-shaped force sensors were carried out by a universal static/dynamic testing machine (H&P Inspect Micro, 10 N load cell). The output voltages O1-O3 versus load, applied on the center of the ring, are shown in Fig. 6. The displacement at a load of 5 N was 13 µm which could not be perceived by the clarinet players. Finally, Fig. 7 shows the hysteresis for sample output 1.

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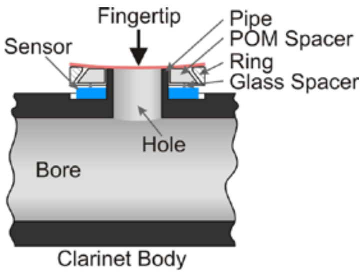

Figure 1: Cross section of the clarinet body with closed hole. The original pipe has been replaced by the ring-shaped force sensor. A POM spacer is used to preserve the original surface.

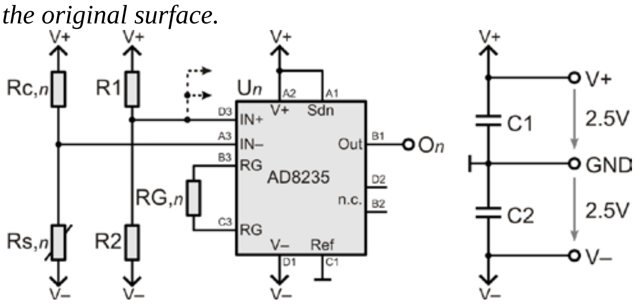

Figure 2: Schematic of the force sensor with bridge circuit, instrumentation amplifier, gain setting resistor and decoupling capacitors.

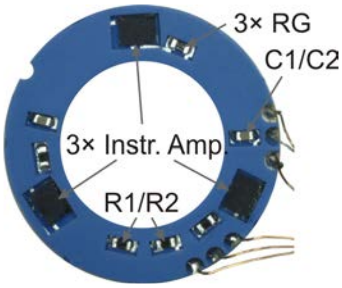

Figure 3: Bottom view of the force sensor. Inner diameter 8.8 mm, outer diameter 14.8 mm, total height about 2 mm.

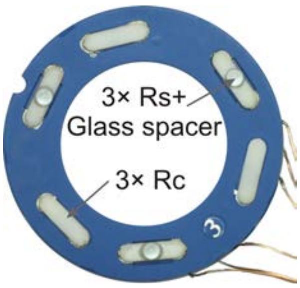

Figure 4: Top view of the force sensor without POM spacer. The active and passive zirconia HTCC sensor elements (white) were embedded into the ring-shaped LTCC package (blue).

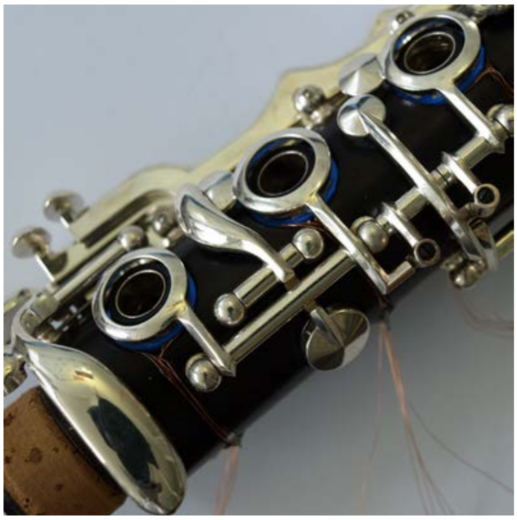

Figure 5: Three ring-shaped force sensors mounted in the upper joint of an Oehler system clarinet.

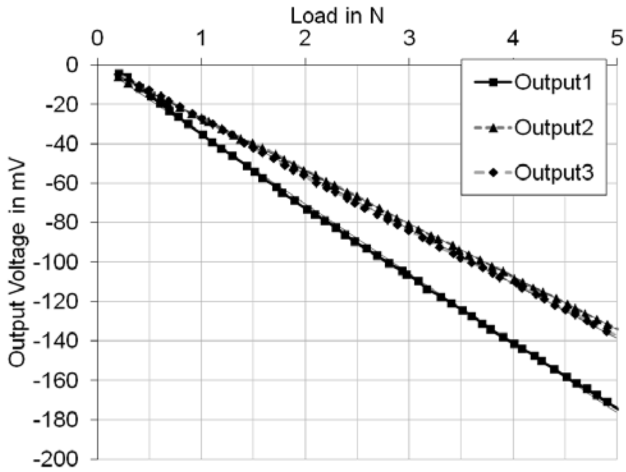

Figure 6: Output voltage of outputs 1 to 3 with load applied to the center of the ring.

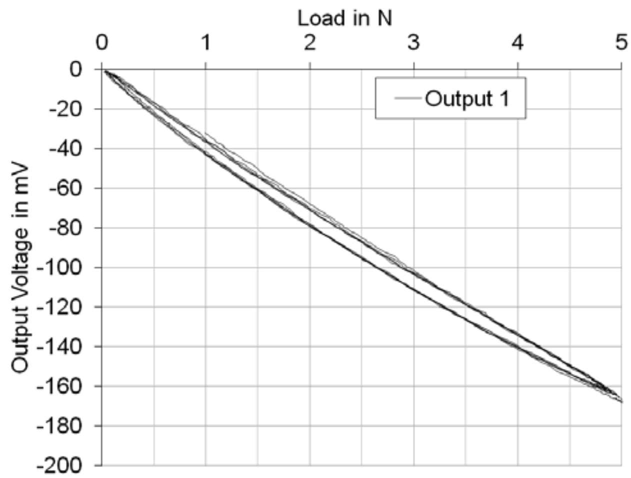

Figure 7: Output 1 with load alternated 5 times from 0 to 5 N, showing a maximum hysteresis of about 0.3 N.