Inline Monitoring of continous Ultrasonic Welding Processes of Thermoplastic Composites via a custom polyCMUT based Ultrasound Array

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Ultrasonic welding (UW) of thermoplastic composites (TCs) is an emerging technology in the field of composite joining techniques in the aerospace sector. Through a mechanical oscillator, ultrasound at a frequency of 20kHz is induced into the material via an ultrasonic horn, where microscopic friction and damping effects melt the thermoplastic. Under further pressure the weld area cools down, permanently joining both parts together. Like all joining processes in the aerospace industry the resulting joints need to be tested for their quality and structural integrity. The traditional way would be to use water coupled ultrasound whereby one has to remove the part from the welding set up, test it, and potentially reinstall it into the welding setup to improve the welding quality. This process could be considerably improved by assessing the quality of the weld directly after or even during the welding process, allowing for immediate rework or discard of the parts in question. Ultrasound is still the best solution for this quality assessment, being inexpensive, well understood, and able to create B-Mode images, allowing a look into the cross-section of the weld. However there are several major problems: To increase the system complexity as little as possible it is necessary to attach the ultrasound unit on the same end-effector as the welding equipment, and as close to the welding horn and compactor as possible to save space and keep the end-effector maneuverable. This brings major problems for classic piezoelectric ultrasonic arrays: The low frequency and its resonance modes reach into the lower resonance modes of the piezoelectric sensors leading to immense noise, hiding any potential echo from the welding zone. Classic piezoelectric crystals are also very brittle and can suffer damage from sustained exposure to this violent environment. The authors therefore want to present a novel solution: a custom made polymer-based capacitive micromachined ultrasonic transducer array (polyCMUT). polyCMUTs are in essence tiny drums with two electrodes. One on the bottom and the other suspended over a cavity sandwiched between two layers of polymers. By applying a DC-bias an electrical field is created and the membrane is set under tension. If then a AC voltage is applied, the strength of the electric field decreases, allowing the membrane to snap back into its original position. If this is done at the resonance frequency of the membrane, a fairly strong ultrasonic signal is created. To receive this signal the polyCMUT is once again charged with a DC-bias, allowing it to receive the echo of the transmitted signal by measuring the changing capacitance due to the movement of the membrane. Not only is the polymer very robust and inexpensive to fabricate, the general architecture of CMUTs also allows a design where the first mode of resonance is the actual mode the CMUT is operating in. By designing for a resonance frequency over 5 MHz all noise from the initial welding process is ignored, leading to a working pulse echo imaging system. The array is then mounted onto a PEEK block attached to the compactor unit of the welding end-effector and glycerin is fed underneath the block via a channel. This publication is intended to present the authors initial results, the design process of the custom array and the tests leading there.