Laser-Assisted Surface Adaptive Ultrasound (SAUL) Inspection of Wire + Arc Additive Manufactured (WAAM) Samples with Complex Surface Profiles using a Phased Array Roller Probe

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Abstract

The market for cost-effective additive manufactured (AM) complex components has evolved rapidly within the recent years urging the practitioners to devise robust non-destructive evaluation strategies to ensure the quality and integrity of such components. Among other AM techniques, Wire + Arc Additive manufacturing (WAAM) has particularly proven to offer high deposition rates allowing to manufacture large-scale near net shape components within shorter lead-times. However, it is difficult to fully control the occurrence of manufacturing defects such as gas pores, lack of fusion, and keyholes, especially when the gas tungsten arc welding provides the process heat. Phased Array Ultrasonics Testing (PAUT) has been one of the preferred long-standing non-destructive evaluation methods used to inspect such weld defects and has a clear potential to be applied in WAAM inspection. Performing interlayer inspection of WAAM reduces the scrappage and re-work time.

For an effective WAAM inspection, it is essential to establish a good contact between the PAUT array and the complex surface of the WAAM. Thereby, an PAUT roller probe with a flexible tire that can tolerate high temperatures (< 350˚C) was designed and developed. The tire accommodates the geometric mismatch between the curved surface of the WAAM and the stand-off delay line within the roller probe – shown in Figure 1(a). Also, it is equally important to correct the PAUT focal laws such that the UT beam is well-focused as the roller probe scans over a WAAM component with a varying surface profile. This enhances and maintains the detection sensitivity along the sample. For this purpose, a Surface Adaptive Ultrasound (SAUL) algorithm was embedded in a robotically delivered inspection system. The system is planned and executed in LabVIEW to interface a KUKA KRC4 robot controller, PEAK LTPA PAUT controller and a Micro-Epsilon laser profiler (see Figures 1(b) and (c)). Required contact and orientation between PAUT roller probe and the WAAM component is maintained through real time force-torque control. During the scan, the surface profile is acquired at a predefined frequency using the laser profiler, and then processed on the fly within the SAUL algorithm to update the PAUT controller focal laws helping to keep in a consistent depth of focus regardless of the changes of the WAAM surface. The system was initially tested on an aluminium reference bock which was specifically designed with a varying surface curvature and flat bottom holes of 1 mm in diameter. The performance is also assessed using a titanium WAAM wall with flat bottom holes. Holes were successfully detected in both studies.

Keywords: Surface adaptive ultrasound, High temperature phased array ultrasound roller probe, Inspection of wire + arc additive manufactured components, Robotically delivered ultrasound inspection

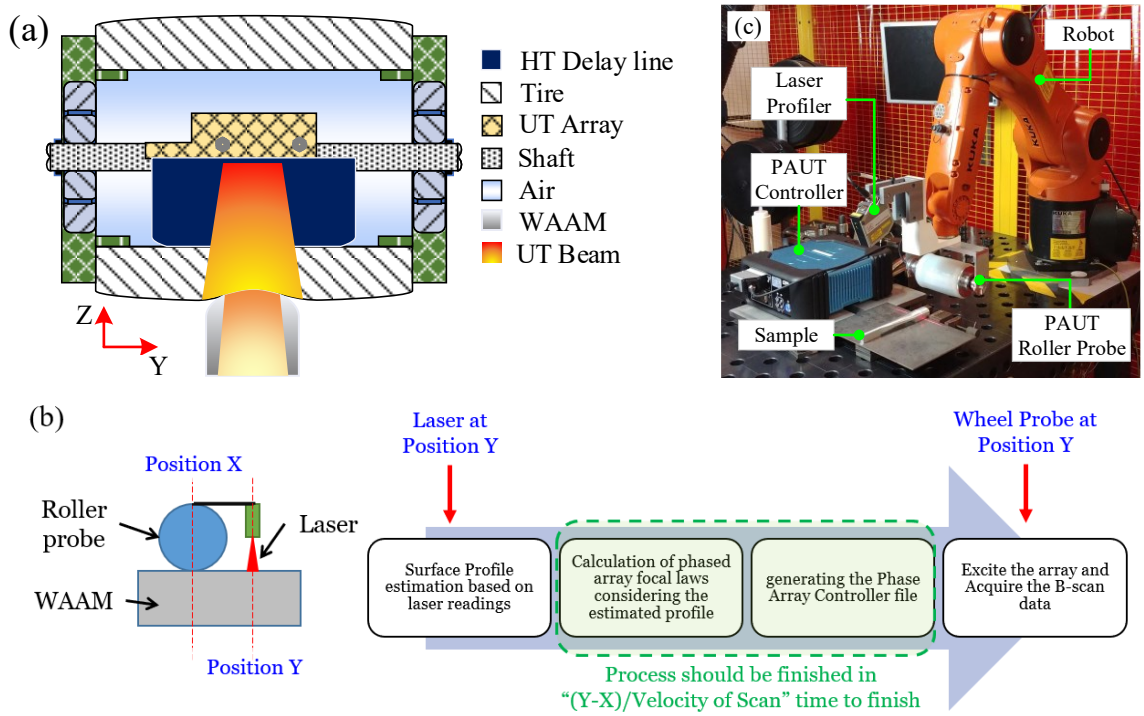

Figure 1 (a) A simplified design of the WAAM high temperature PAUT roller probe, (b) integrated robotic system for the inspection of WAAM including the roller probe, PAUT controller and the laser profiler, and (c) plan for laser-assisted on-line correction of PAUT focal laws as the roller probe scans a sample with changing surface profile