Coherence ultrasonic imaging applied to the inspection of industrial parts

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Ultrasonic imaging with phased array probes is now widely used in non-destructive testing (NDT). Standard reconstruction algorithms such as TFM (Total Focusing Method) and PWI (Plane Wave Imaging) which are based on the Delay-And-Sum (DAS) technique are generally used because they are fast and easy to implement and interpret. These techniques simply consist of delaying and summing linearly the signals received by the transducers in order to naturally exploit the coherence of acoustic signals. Ultrasonic echoes returning from the same reflector and delayed by their proper time-of-flight value are in phase. Therefore, the summation of their contribution in the reconstructed image is greater than the summation of incoherent information that are not in phase (grating lobes, secondary lobes, reconstruction artifacts, measurement noise, electronic interference, etc.). Nonetheless, non-destructive testing applications are extremely diverse and sometimes highly complex. In such cases, DAS algorithms may not effectively cancel out unwanted contributions from ultrasound signals and reconstructed images can be difficult to interpret due to lack of resolution or contrast. Numerous reconstruction algorithms designed to enhance the coherent contributions of summation exist in the literature, particularly in the field of medical ultrasound. These methods are highly promising because they can improve the quality of reconstructed images with same dataset and without restricting the inspection rate. While these approaches offer substantial benefits, they are not universally applicable nor devoid of drawbacks. We propose to evaluate the relevance and effectiveness of the following coherence imaging algorithms in a non-destructive testing context: Phase Coherence Imaging (PCI), Nonlinear Amplitude Compression Imaging (pDAS), Instantaneous Phase Coherence Imaging (IPCI). The proposed techniques have the advantage of being fast (close to DAS) and providing easily interpretable results, enabling them to be integrated into real-time inspection systems. In addition, they can be used in parallel with a DAS reconstruction, providing a complementary analysis to standard methods. We show that images reconstructed by coherence methods deliver better results than DAS on typical industrial NDT applications, such as the inspection of coarse-grained steels, cracks detection, or the characterization of HTHA (High temperature hydrogen attack) damage. The paper also provides insights into specific conditions and applications where these techniques excel, creating a nuanced understanding of their performance boundaries. Through this analysis, the paper aims to help NDT professionals and researchers to make informed decisions on the selection and implementation of coherence methods and hence to significantly improve the efficiency, accuracy, and effectiveness of their NDT processes.