Nonlinear ultrasonic phased array imaging for closed cracks

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Although ultrasonic testing (UT) has a high sensitivity to cracks, UT has often encountered the problem that the crack closure due to compressive residual stress or by oxide film generation between crack faces weakens crack response. Furthermore, other unknown linear scatterers (e.g., coarse grains, welds, geometric change) can lower signal-to-noise ratio (SNR). To realize high-selectivity crack imaging, various types of nonlinear ultrasonic phased arrays that combine nonlinear ultrasonics with PA have been studied. One of the promising methods is a fixed-voltage fundamental wave amplitude difference (FAD) [Y. Ohara, et al., J. Acoust. Soc. Am. 146 (2019) 266]. Fixed-voltage FAD is based on measuring the incident-wave-amplitude dependence of fundamental waves because the energy of the nonlinear components generated at cracks is distributed from fundamental components. This enables us to measure all nonlinear components generated at closed cracks without directly measuring specific nonlinear components (such as subharmonics or superharmonics). We have also developed another promising technique that combines pump wave (kHz) with ultrafast PA imaging (MHz) based on plane wave incidence [Y. Ohara, et al., Appl. Phys. Express, 14 (2021) 126505]. Note that the pump wave (kHz) is utilized to excite a very high displacement of 1000 nm, which is much greater than the upper limitation for MHz frequency. The high-speed contact vibration of crack faces caused by the pump excitation is captured by ultrafast PA imaging at thousands of frames per second. In this study, we will show some results obtained by those nonlinear ultrasonic phased arrays, in addition to clarifying the advantages and disadvantages of each method.