Simulation and optimization of dual-linear array probe design for the UT detection and characterization of stress corrosion degradation on the safety injection system lines of the French nuclear reactors

Bastien CLAUSSE[1], Olivier WATTIAU[2], Francois BILLY[2], Sebastien LONNE[1]

[1]Consulting, EXTENDE, France, [1]Direction Industrielle, EDF, France

During the regulatory inspection of the nuclear facilities of Civaux unit 1, scheduled in autumn 2021, nondestructive evaluation (NDE) carried out on the pipes of the safety injection system (SIS) revealed the presence of unexpected damages linked to Intergranular Stress Corrosion Cracking phenomenon (ISCC). As a precautionary measure, 14 units potentially affected by the phenomenon were gradually shut down (for preventive or early maintenance). Investigations showed that a new NDE design was required in order to restart these reactors and ensure electricity production very quickly. Indeed, the current techniques implemented were too limited for this issue. Thus, an innovative NDE technique was reactively developed and implemented on site by EDF with the support of its partners in order to detect and characterize reliably potential cracks. Significant difficulties such as material and geometry (thick austenitic steel lines made up of tubes and elbows, thickness of weld pass, taper weld, etc.), defect properties (ISSC crack with 2 mm height and over), an accurate height sizing, as well as the conditions of application on site (operators and analysts training, accessibility, dosimetry) led EDF to design an advanced NDE technic based on FMC-PWI acquisitions associated to TFM reconstructions and using a manual encoded scanner. On the one hand, a dedicated scanner was developed in order to be directly set on the welds of the SIS pipes. On the other hand, a dual linear array probe at 4 MHz was designed and optimized with numerical simulations (CIVA UT) and then manufactured. A first NDE system was tested on cut pipes which were removed from sites for metallurgical investigations in laboratory. The results showed that UT indications were well correlated with the numerous destructive characterizations of ISCC cracks (good detection, height sizing and assessment accuracy). The final NDE system was deployed on sites as of August 2022. The purpose of this paper is to describe the methodology used by EXTENDE with CIVA UT software to optimize in a very short amount of time the phased-array probe that was designed and then industrially deployed on the units of the French nuclear fleet. Indeed, to optimize probe parameters as quickly as possible considering all the different inspected geometries, CIVA UT advanced features and tools have been applied such the extraction of user-defined analysis criteria and parametric studies with metamodels. This paper illustrates the simulation methodology deployed for this industrial application case and discusses advantages, limitations and perspectives of the use these advanced simulation tools in NDE method development.