NDE: The Road to NDE 4.0 and Beyond

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The term NDE 4.0 appeared about 7 years ago. Some people say: "This is just a new label to make money". However, NDE 4.0 is a term which describes technical innovations that we are currently seeing in both industry and in wider society. Any improvement in production technologies always required an improvement in methods for verifying product quality and integrity, and which give an assessment without destroying the product. Classical methods for detecting and locating defects at the end of the production process were called NDT (Nondestructive Testing). Improved methods have made it possible to measure the size, shape, orientation and physical properties of defects and give material characterization. These provide important information for (i) improving production quality and (ii) monitoring growing defects in aging structures (fatigue, creep, corrosion). These measurement modalities have been termed NDE (Nondestructive Evaluation). An even more quantitative approach, called Quantitative NDE (QNDE), was developed to provide data that helped (i) decide if a defect is of a critical type and size, when a structure is subject to certain stressors, or (ii) the defect characteristics and loadings can be used as input for prognostics, to predict the future life of a component in use. The performance and reliability of NDE methods and their implementation can be statistically evaluated and forms the basis for the inspection performance metric, Probability of Detection (POD). Advances in computer based digital technologies are impacting most industries, and digital NDE techniques are being seen to provide more reliable and repeatable inspection results. These technologies have now enabled the beginning of NDE data banks and sophisticated data analysis techniques. As early as 1992, it was proven in trials, that digital image processing detected and correctly classified more welding defects than human inspectors. Neural networks were also tested in NDE in the 1990s and these can be considered as early forms of artificial intelligence (AI), although they were primarily used in laboratory settings. At that time, the industry was looking for automated inspection techniques within the production process to enable detection of defects at an early stage of production. However, this was based on rigid standard procedures, with use of robots or CNC machines, where data were obtained when a large number of similar parts were produced. At this time the NDE inspection results were finally assessed by an inspector. Within today's cyber-physical production systems, all machines can, potentially, communicate with each other and exchange and modify the production parameters so that individual products can be created (Industry 4.0). This type of process poses challenges for NDE in two ways: 1. Quality assurance and inspection must be integrated into this intelligent and self-learning flexible production environment and 2. Decisions which assess the significance of "anomalies" must be made for unique parts, solving both the inverse characterization problem and assessment in terms of a prognostic, when a part has a specific expected use, lifespan and loads. This requires incorporating modeling through the use of digital twins, self-learning, artificial intelligence and much more. By assessing previous NDE results AI can potentially help to improve the NDE methods step by step, particularly in the context of unique parts. NDE data can, when used as input, help to guide smart production devices, such as with additive manufacturing, to improve processes and product quality. We can call this next generation process and assessment NDE 4.0, that can also be seen as the cyber-physical transformation of NDE. In the future, we can expect to see a holistic healthcare system for complex engineering products such as cars, trains or planes that is analogous to the human healthcare system. This will include continuous monitoring throughout production and then monitoring the products in service. That brings together NDE and structural health monitoring (SHM), intelligent diagnostic methods (QNDE) that generate enormous amounts of data, stressor data and prognostics to determine the future integrity of products. Artificial intelligence using "symptoms" (SHM data) and "diagnostic results" (NDE4.0) plus detailed knowledge of the product stressors in use and resulting load parameters (in digital twin) will, in the future, guide how best to apply NDE and how to potentially use a component, with a known population of anomalies, under specific loads/stressors. The author will illustrate these steps of NDE development using examples from his 45 years of experience and NDE.