Application of dimensional analysis in the era of NDE 4.0

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Non-Destructive Testing and Evaluation (NDT&E) problems often entail several different factors. As a matter of fact, the results of an NDT&E test depend on (i) the physical and geometrical characteristics of both the probe and the sample under test, and (ii) the geometrical parameters describing the relative position between the probe and the sample. The challenge in the solution of NDT&E problems is strictly connected to the number of involved variables and their complex nature. To this purpose, a methodology that can systematically reduce the complexity of the NDT&E problems to be faced by decreasing the number of involved variables can play a very important role. The reduction of the number of variables has a major impact on the NDT&E problem solution when it is physically modelled either via a numerical approach or via a machine learning approach. In both these cases, there is an exponential reduction in the number of required numerical simulations or the size of the training database. To this purpose, dimensional analysis is a useful tool for analyzing problems involving several physical quantities. Through dimensional analysis, unknown functional relationships can be revealed by studying ad-hoc dimensionless quantities that catch the entire physics of the problem under consideration. Specifically, it is possible to identify a smaller set of fundamental variables that accurately describe the original problem by just analyzing the physical dimensions of the variables included in an equation. This simplifies the computation of the solution of the original problem. The celebrated Buckingham's π theorem is relevant in the context of the reduction of variables describing a physical problem to the essential ones, through dimensionless quantities, the so-called π groups. The specific application of Buckingham's π theorem in NDT&E depends on the considered method and the variables that affect its performance. Each NDT method may have its own set of relevant parameters and specific π groups. In addition, this theorem is a valuable tool that can lead to more efficient and effective inspection processes. In order to show the effectiveness of dimensional analysis, an in-depth analysis and application of the theorem have been investigated to the most commonly applied NDT methods such as ultrasound, eddy current, thermography and magnetic flux leakage. In this contribution, we propose different methods for the simultaneous estimation of two quantities of interest based on Buckingham's π theorem. The proposed method allows to reduce the complexity of the problem while ensuring high accuracy and real-time operations, for in-line and on-line simultaneous estimation of the parameters of interest in industrial applications. For example, two particular applications of the theorem will be presented on the ultrasound method for the simultaneous estimation of the thickness and propagation speed of waves, and on the eddy current method for the simultaneous estimation of the thickness and electrical conductivity of metal plates. This specific application is motivated by the fact that measuring the thickness, wave propagation speed and electrical conductivity of metallic materials is an important factor in all production and manufacturing processes (e.g., pressing, rolling and heat treatment). In fact, these three quantities directly influence the quality properties of finished products, such as hardness, toughness and tensile strength. In this scenario, accurate, real-time monitoring of the thickness and electrical conductivity of metallic materials is essential to improve production quality and efficiency. In-line measurement techniques are essential because they enable automatic quality control during the production phase, ensuring products or materials with appropriate accuracies, reasonable costs and reduced inspection times, as required by the Industry 4.0 paradigm. The results obtained in the various applications demonstrate the goodness and potential of the method. Furthermore, the method appears to be perfectly suitable in the context of NDE 4.0 by supporting technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Big Data and Cloud Computing.