

Digital Condition Monitoring of Nuclear Piping-Equipment Systems using Artificial Intelligence technology

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Abstract

Artificial Intelligence (AI) based structural health-monitoring frameworks explore the applicability of deep learning algorithms for assessing the health of various systems such as aerospace and aircraft industry, mechanical and civil engineering fields, energy sector, industrial power plants, etc. Currently, the nuclear industry is focused on developing advanced nuclear reactors with autonomous control systems and digital twin technology. The implementation of digitized next generation nuclear reactors can enable a high output of carbon free power generation to meet the increasing global demands for electricity. Ensuring safe operations at nuclear facilities while reducing the associated maintenance life-cycle costs is important. Nuclear systems such as piping-equipment systems can experience aging and degradation over time due to flow-assisted erosion and corrosion. This leads to pipe-wall thinning and subsequent cracks in the piping system. These systems can also undergo vibrations due to various normal operating loads, such as pump-induced vibration loads. The dynamic phenomenon of vibrations in equipment and connecting systems is a common occurrence in engineering practice. Undetected corroded locations can be subject to a build up of cyclic fatigue due to operational vibrations and thermal cycles. A leakage in a vital piping system of a nuclear facility can result in accidents such as loss of coolant accident (LOCA). Cracking due to fatigue as well as erosion and corrosion can be minimized by early detection of pipe-wall degradation. Therefore, this research presents a digital condition monitoring framework for nuclear piping-equipment systems using AI technology, to identify degraded locations and their severity level well in advance of a crack developing in the pipe material. For the application case study, the proposed methodology is implemented on the Experimental Breeder Reactor II (EBR-II) nuclear reactor Z piping-equipment system. A finite element model of a nuclear piping system is designed and subjected to pump-induced normal operating loads. Sensor data is collected from optimally placed sensors on the system. A new feature extraction technique is proposed to extract a vector of degradation-sensitive quantities from the sensor data and create a database repository for training the AI framework. A multilayer perceptron (MLP) is designed for detecting the degraded locations and classifying the severity as minor, moderate or severe. Continuous condition monitoring can result in lowering the maintenance costs along with extending the operating lifetime for a nuclear power plant.

Keywords: Condition Monitoring, Deep Learning, Neural Networks, Feature Extraction, Nuclear Piping