Advanced Instrumentation, Information, and Control Systems Technologies

Online Monitoring of Material Aging and Degradation in Nuclear Power Plants

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October 13, 2016

Light Water Reactor Sustainability R&D Program
Research Team

- Research Funded under the Advanced Instrumentation, Information, and Control Technologies Pathway
- Idaho National Laboratory – Lead Institute
  - Vivek Agarwal and Andrei V. Gribok
- Vanderbilt University – Lead University Partner
  - Profs. Sankaran Mahadevan and Douglas Adam
- University of Alabama Tuscaloosa
  - Prof. Eric Giannini
- Oak Ridge National Laboratory and University of Tennessee Knoxville – Activities funded by the Material Aging and Degradation Pathway
  - Yann LePape, Dwight Clayton, and Prof. Ma
Project Overview

• Online monitoring of passive structures
  – Concrete structures
  – Secondary system pipes

• Support long-term and reliable operation of current fleet of the U.S light water reactors

• Develop a structural health monitoring (SHM) framework that can be extended to other material aging and degradation
Present Challenges

• Age-related deterioration of plant structures
  – Physical, chemical, mechanical and radiological degradation
  – For example, alkali-silica reaction (ASR) in concrete structures and corrosion in piping systems

• Lack of advanced technology solutions
  – Periodic visual inspection
  – Localized non-destructive evaluation

• High operational and maintenance cost due to scheduled or unscheduled downtime
  – To remain competitive in energy market
  – Increase operational efficiency and productivity

• Current SHM in the nuclear industry is strictly NOT ONLINE
Concrete SHM Framework

**Monitoring**
- A variety of NDE techniques can be used
- Full-field techniques investigated: thermal imaging, digital image correlation (DIC)
- Vibration-based techniques

**Data analytics**
- Process the raw monitoring data for diagnosis
- Consider heterogeneous and large data sets

**Uncertainty quantification**
- Integrate all available information and facilitate risk quantification

**Damage modeling**
- Leverage existing modeling efforts
- Use diagnosis result for prognosis
Concrete Samples

• Three 9- x 5- x 2-in. concrete samples
  – Glass and various aggregates
  – Baseline sample cured in water
  – Reactive sample cured in NaOH

• Large concrete sample 2 ft x 2 ft x 6 in.
Vibro-Acoustic Modulation (VAM)

- Low-frequency “pumping” signal and high-frequency “probing” signal
- A nonlinear system can be identified by interactions between the two inputs, or the system’s linear response to each individual input

*Modulation is specifically a product of responses that manifests in the frequency domain as a convolution of spectra

\[ \cos(\omega_1 t) + \cos(\omega_2 t) \]

*Modulation term

\[ \cos(\omega_1 t) + \cos(\omega_2 t) + \cos(\omega_1 t)\cos(\omega_2 t) \]
Vibro-Acoustic Modulation - Result

VAM Experimental Set-up

VAM Spectrum on 3 concrete samples
Digital Image Correlation (DIC) Set-Up at UTK
Digital Image Correlation (DIC) Set-Up at UTK

- Speckle patterns and durability test of paint under high relative humidity of the environmental chamber

Oil-based paint

Acrylic latex

Speckle patterns on UTK sample
Other Accomplishments

• Monitoring Techniques
  – Infrared thermography and Nonlinear Impact Resonance Acoustic Spectroscopy were performed on concrete samples

• Data Analytics
  – Heterogeneous large data set were processed and MapReduce was implemented

• Uncertainty quantification
  – Integrate all available information and facilitated uncertainty quantification
Technology Impact

• The framework is extendable to other passive structures

• Would enable online monitoring of aging passive structures to support long term sustainability of nuclear plants

• Introduce advance technology solutions

• Maintain economic competitiveness of the nuclear industry in the US energy market
Summary and Path Forward

- Different monitoring techniques were evaluated to study ASR degradation on concrete samples.
- Vibro-acoustic modulation seems to provide insight on degradation due to ASR.
- Digital image correlation instrumentation were installed at the large concrete sample at UTK.
- Heterogeneous data were analyzed and MapReduce methodology was implemented.
- Uncertainty quantification based on different available information was performed.
Path Forward

• Further investigate application of VAM on concrete samples made of different reactive aggregates (provided Univ. of Alabama)
• Cross-verify VAM with chemical changes in the concrete mix using chemical sensors (for example, Strain and pH sensors)
• Continue to collaborate with ORNL and UTK to collect DIC data and study ASR degradation in large concrete samples
• Initiate work with University of Nebraska – Lincoln awarded under the Nuclear Energy University Program on concrete SHM
• Engage industry participation
Milestone Reports and Publications

- Two level 2 milestone reports were completed


- Mahadevan et al. Quantitative Diagnosis and Prognosis Framework for Concrete Degradation Due to Alkali-Silica Reaction. QNDE Conference, Atlanta, GA, July 2016.