Next-Generation Historical Data Comparison: A Defense-In-Depth Approach to Automated Nuclear Steam Generator Testing

Industry White Paper

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The Widening Gap Between Safety Requirements and Available Resources

When managing coolant levels in a nuclear power plant, no single line of defense provides sufficient protection. This is the basis of nuclear steam generator testing during plant outages. Redundant processes of primary and secondary analysis, resolution, and review are time- and resource-intensive, but they ensure that areas of potential tube degradation are identified early so they can be addressed without incident. An additional line of defense is to "address history" by comparing current tube inspection results against historical results based on common characteristics to determine what changed and whether the change warrants protective action. Unfortunately, existing technology hasn't allowed for this comparison of historical and current data to be applied to anything more than specific identified areas of concern, not the entire tube, and even historical context is typically limited to a single comparison timeframe. And with multiple steps required to prepare both sets of data for evaluation, this is a labor-intensive activity to add to an already overtaxed analysis process.

With pressure to minimize downtime for testing during the outage, inspection managers have been challenged to manage the widening gap between safety requirements and available resources. In recent years, automated testing systems have evolved to help alleviate some of the workload. Large amounts of tube data can be produced in a short timeframe and computers with automated analysis software can process this data quickly and consistently, allowing human analysts to apply their unique perspective and expertise to validate those results. But inspection managers are still left facing a common conundrum: how to balance time, personnel, and project scope to address the gap between inspection requirements and the resources available to support the process.

For most plant inspections, increasing the downtime window for testing during an outage is simply not an option, and the use of automation to perform the initial analysis has already yielded its greatest returns. And while automation and other efficiencies have helped compress the testing timeline, they have also intensified the need for timely human analysis and decision-making relative to the overall testing timeframe. To meet that need, inspections could use supplemental trained personnel to review and resolve reportable indications flagged by automated (or manual) analysis, but quickly adding personnel during an inspection is not a realistic solution. Site access training requirements alone put this option outside of the already-compressed timeline. And as the current population of experienced analysts ages out of a career that is highly repetitive and fatiguing—and that doesn't provide compelling opportunities for a new generation of analyst—the shortage of qualified analysts will likely become more pronounced over time.

The remaining option—to change the scope of the inspection and eliminate some of the review—is far from ideal but is what many inspection teams are facing. This runs in direct conflict with inspectors' needs to anticipate or identify problem areas outside of those already pinpointed during the stressful and fatiguing inspection processes. Fortunately, a new generation of historical data comparison (HDC) promises the most effective approach yet for managing this widening gap between safety requirements and resources. Intelligent, full-tube HDC combines automation technology with human instinct and experience-based expertise. The technology becomes an integral part of an automated analysis system by providing not only automated, multi-inspection addressing of current to historical flaws, but also a new method of detection based on change when historical data is available.

This is a new approach that can replace redundant systems with true defense-in-depth. Human analysts gain access to a comprehensive yet manageable data set to apply for faster and significantly improved inspection accuracy. At the same time, the independent and complementary processes help mitigate the possibility of a missed change that may not meet reporting criteria, but is of significant interest in steam generator tubes that could result in human or environmental loss.

Current Variants in Historical Data Use

While historical data comparison has been used for some time in nuclear steam generator testing, the technology has recently taken huge strides. Historical data use approaches are not created equal, and it is important to understand the differences in available technologies and applications, as well as the advantages and weaknesses of each.

Historical Report Line Comparison

Historical report line comparison allows a resolution analyst to compare historical and current report lines for an identified anomaly. The report lines describe the anomaly found and its location, plus the phase and amplitude of the eddy current result. And when automated, this report line comparison is effective at identifying high-magnitude changes—especially fast-growing and new flaws. However, because these report lines are not calibrated to each other, precise measurement requires extra effort to correlate these disparate data sets. Also, report line comparison is less effective at highlighting small or incremental changes with a high degree of accuracy because it doesn't compare actual data. Although it has the advantage of working with all analysis techniques, it still requires the labor-intensive process of comparing actual data to resolve the results. Particularly for plants with large inspection data sets, the time required to calibrate and compare data points and draw effective conclusions can be prohibitive.

Historical Data Segment Comparison

A more effective approach is to automatically compare segments of the current data with corresponding segments of the history data where the current analysis has reported degradation. For this approach, selected history and baseline raw data segments are loaded for the current tube, set-up parameters are adjusted, and algorithms are applied to correlate both data segments. This allows the analyst to view a result of the mathematical comparison in the actual eddy current data segment, not just absolute values. While the benefits of historical data segment comparison take it a step beyond historical report line comparison, this approach is still dependent on another process to bring in candidate-reported degradation to interrogate for change. By definition, the process is not comprehensive, making it unreasonable to use to address entire data files. Instead, analysts are typically presented only flagged segments with reported degradation within the data file and may miss related changes in other areas.

Correlated Data File Comparison

By far the most comprehensive and effective approach to historical data comparison is to compare complete available data files using sophisticated correlation, alignment, and calibration algorithms. The process can then process the subtraction of the two files to create a "delta" channel that shows only change, allowing the analyst to see change throughout the entire data file. In addition, the independently processed channels can be visually displayed in overlay with the corresponding historical channel, giving the analyst an unprecedented view of the flaw over time to better understand flaw morphology. Correlated data file comparison is agnostic to regions of interest and data-acquisition and -analysis methods, requiring only similar techniques and complementary data files. This new technology automatically compares current, historical, and baseline data for every available tube of bobbin data in the current inspection. Analysts can quickly review detected change reported by the automated analysis of the delta channels and can visualize the flaw morphology through the overlay of the processed data. Sophisticated software allows rules to be applied to report desired change in amplitude and/or phase, providing new detection opportunities that could be missed using legacy technologies. With this capability, all reported change can be quickly reviewed, resulting in the ability to process not only identified areas of concern, but also any change that wasn't highlighted by other automated or manual analysis processes. Overall, this process provides quick, automatic detection and reporting of change using more complete historical data than other processes have access to, and provides the analyst with visualization tools to understand the change.

Technology Advancements Drive New Capabilities

The advantages of next-generation HDC have only recently been viable due to technology evolutions that have advanced the science of historical data comparison. When the HDC concept was initiated, available computing power limited the ability to process data quickly enough within the analysis window. Additionally, disparate data sets from the same location couldn't be effectively correlated based on speed of data acquisition. Two key evolutions enable today's new capabilities: powerful computer processing, and the development of sophisticated algorithms. Together, these offer significant new opportunities for time-sensitive performance, improved analysis and resolution, as well as flexible and scalable implementation to meet a wide range of testing needs. As a byproduct of these evolutions, advanced visualization capabilities allow the technology to be implemented practically and efficiently.

Distributed Processing Power

The combination of powerful multicore computers and distributed processing farms allows HDC software to efficiently process entire data files in a timely manner. Real-time capabilities can now be integrated into the current analysis process, ensuring that the analysis team can perform the required addressing of historically reported degradation for change without impacting the schedule or resources. This also allows real-time examination of data change on entire tubes, not just segments, so the analysis process doesn't miss emerging degradation in unprocessed sections of the tube.

Algorithm Development

Sophisticated algorithms allow the software to correlate and interpolate even disparate data gathered from multiple inspection techniques. Analysts can easily align prominent features for additional examination, and compare voltages and rotations. Advanced algorithms such as these can accommodate variations in acquisition speed, changes in test direction, and variations in calibration without effecting the change analysis.

Interface and Visualization Advancements

An intuitive user interface and responsive, high-resolution visualization tools allow analysts to easily define and view current, baseline (or any available historical timeframe), and delta data sets. Data is plotted on a color-coded Cartesian system and strip charts that show signals within correlated space for highly efficient understanding of the morphology.

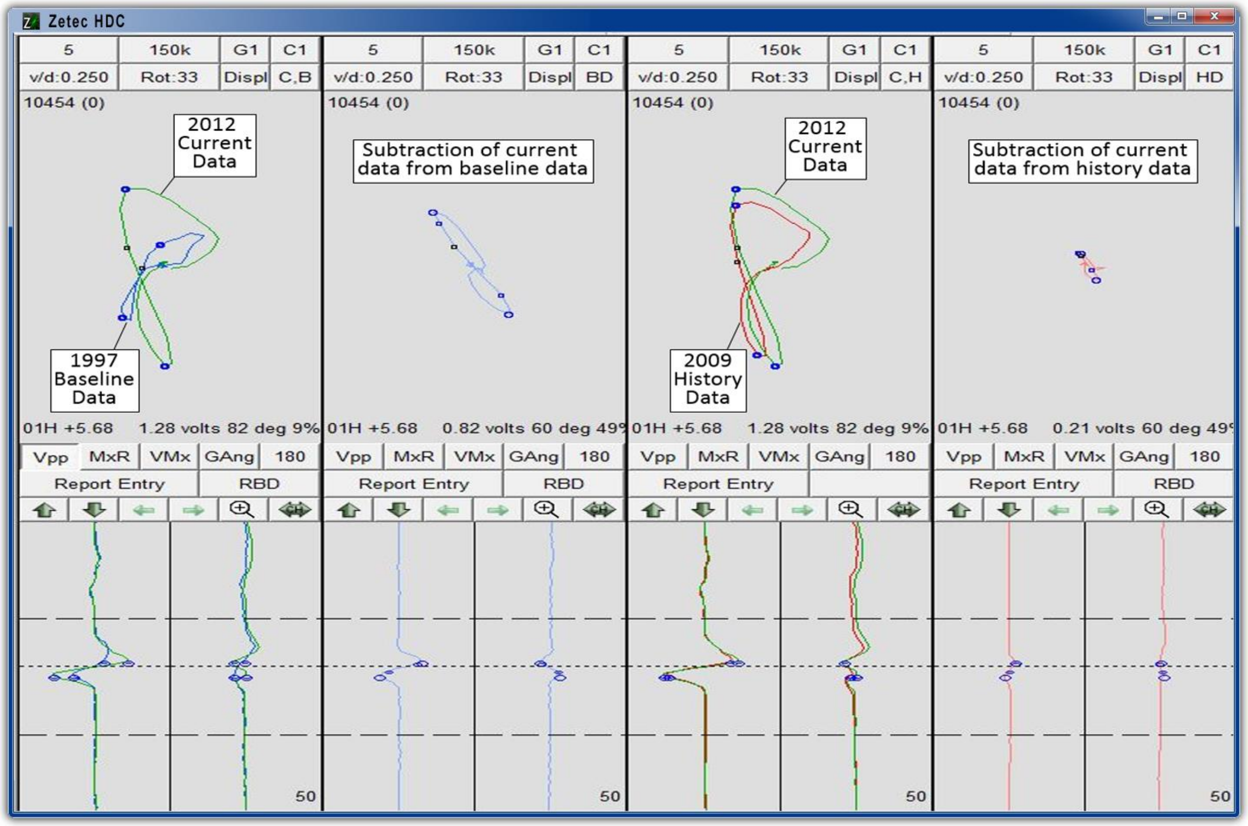

Figure 1. Zetec Historical Data Compare plots comprehensive tube data on a color-coded Cartesian system and strip charts that show signals within correlated space for highly efficient understanding of tube morphology.

Functional Usage of Next-Generation HDC within an Automated System

HDC as part of an integrated automated system can be used in each process independently or across all tube inspection processes. Efficiently comparing current data against historical data based on common characteristics improves visual understanding of changes over time and supports ongoing condition monitoring. These capabilities can help dramatically reduce human performance concerns during analysis, and provides higher POD as an independent and complementary detection method. New technology makes this approach scalable and cost-effective, and offers additional use cases for even greater value. For example, today's comprehensive HDC can be used for confident tube identification verification, since complete data files from different tubes will contain unique data fingerprints that can be quickly compared using HDC.

Auto-Analysis Systems

As part of an auto-analysis system, HDC's prepared delta channel can be fed into the analysis process of the automated analysis system, using defined reporting parameters as needed to provide an independent and complementary detection method with respect to change. The correlated data file comparison of HDC is agnostic to regions of interest and data-acquisition and analysis methods, which makes it less prone to the complexities of configuring traditional auto-analysis software. The change detection provided by HDC in an auto-analysis system can be paired with the results produced from traditional automated analysis algorithms, allowing additional logic to be applied to assist in indication confirmation and classification.

Resolution Process

HDC makes addressing history in the resolution process much more efficient, with correlated, overlaid signals that provide immediate visualization of flaw morphology. With correlated historical data at their fingertips, resolution analysts can clearly see degradation change over the acquired data intervals, providing an understanding of flaw morphology not previously available. And with complete data sets, auto-analysis systems can be used to address large populations of indications, such as automatically comparing manufacturing burnish marks. This provides a new, highly effective way to close the gap between requirements and resources.

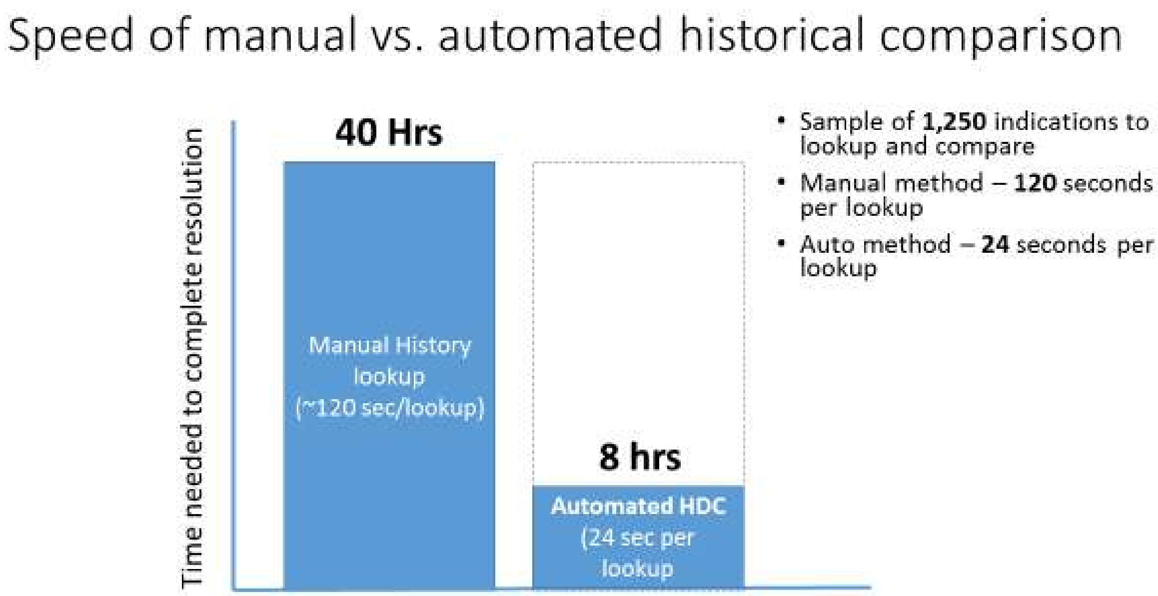

Figure 2. Actual comparison of time required to complete resolution using traditional manual processes versus Zetec HDC software.

IQDA Process

Combining the advanced visualization capabilities of correlated and overlaid signals along with prepared delta channels, the IQDA has a more efficient framework to evaluate the analysis process and performance. Exceptional HDC visualization capability lets the IQDA see the full picture of inspection results for review, rather than the typical limited view. Scrolling through an HDC delta channel gives the IQDA an immediate, unprecedented view of the change in data, without the distraction of interrogating signals that have not changed since prior inspections.

It's Time for a Defense-In-Depth Approach to Automated Nuclear Steam Generator Testing

In the nuclear industry, the ramifications of poorly informed decisions can affect human and environmental health. Rather than continuing to depend on redundant processes, nuclear steam generator testing requires a defense-in-depth approach that adds new, valuable information to the process within the defined timeline and project scope, and that allows the limited population of expert analysts to focus on what they do best—leveraging their experience-based expertise and instinct. The only feasible way to access and include all available data when performing an inspection is to utilize an automated system that has a comprehensive HDC algorithm built in that can process and present the results to the responsible personnel. This supports two critical functions: the ability to quickly address large historical data sets that provide new information for better decision-making, plus new capabilities for independent and complementary detection based on complete historical comparison.

Outage managers who have been struggling to meet stringent requirements in compressed timeframes now gain new confidence. An analysis process that has access to timely HDC information lets them validate appropriate action, and they have a closed-loop process to reduce the risk of missed changes. The automated process ensures accuracy, repeatability, and consistency and alleviates concerns of human fatigue and performance variation. And the automated, algorithm-based approach to accessing, comparing, and presenting results supports optimal human decision-making and provides a next-generation defense-in-depth approach that goes beyond other detection measures.