BACKGROUND OF EDDY CURRENT ANALYSIS SOFTWARE

A wide variety of eddy current software programs are in use for non-destructive examinations today. The degrees of sophistication and performance of these software applications vary, and typically increase with the complexity and requirements of the particular non-destructive examination. Basic examinations of a few components using single coil-pairs in impedance modes may be performed with simple software programs that show Lissajous and strip chart displays. These programs are used in a range of portable tests to determine a “good” or “not good” result for a particular measurement and in straightforward remote examinations. As components become more intricate or contain more parts to examine, the eddy current software must have capabilities to store and retrieve an extensive set of results, typically in the form of calls (or report entries) in a database. As the degradation and component conditions to be reported become more multifaceted, the eddy current software must provide a way to enter different condition descriptions for manual analysis examinations. For automated analysis examinations, the eddy current software must be able to not only detect indications of interest, but also differentiate between reportable indications and correctly denote and annotate their report entries. For examinations of safety-critical components, eddy current software programs must meet industry standards and requirements with increasing rigor.

For an examination that is both complex and critical, such as a steam generator inspection, there are a small number of eddy current software programs available. Most of these applications are produced by either NDE vendors that sell software and hardware products or by inspection service companies that create and use their own examination software. In the case of steam generator examinations, many of the utility customers require or desire specific functionality and results, and eddy current software with custom features are best suited to meet these utility-specific or regional-specific needs. In a time period of fiscal conservatism, the relatively small number of users for a sophisticated software product creates an economic challenge for software vendors. As a result, inspection service companies have found benefit in designing their own eddy current software products to best meet their customers’ inspection needs. Additional eddy current software capabilities have been developed or supplemented by the academic community. Universities have been used to research specific eddy current software applications and advancements. As with any research, these academic research projects produce various degrees of success and usefulness for applications in field examinations.

AREVA has extensive experience providing eddy current examination services to customers worldwide. Headquartered in Paris, France, AREVA has three major NDE Solutions divisions in France, the United States, and Germany. To meet a variety of utility inspection needs around the world, AREVA has used both vendor produced software products as well as AREVA’s own in-house developed eddy current software. To provide optimum inspection capability, AREVA has made significant investment in increasing the capability of AIDA, AREVA’s eddy current analysis program, incorporating best practices from multiple customers and more than 30 years of inspection experience. Such development is achieving AREVA’s goal to make AIDA the eddy current analysis software of choice in the NDE industry. This paper discusses AIDA, the eddy current analysis software, summarizes its capabilities and highlights its recent breakthrough developments. 
INTRODUCTION TO AIDA, THE EDDY CURRENT ANALYSIS SOFTWARE

Development for the AIDA eddy current analysis software program began in the early 1990s, as a program to automate the analysis of bobbin data for examinations of EDF steam generators. Today, after over 20 years of continuous improvements, AREVA has multiple versions of AIDA that serve both commercial and noncommercial customers and serve utilities in eddy current examinations around the world. In the past 10 years, an AIDA version adapted for the US market has served at 24 sites and 34 units through 76 deployments, and is now AREVA’s analysis software of choice for eddy current examinations. In 2011, AREVA announced plans to improve manual analysis and add capabilities for analysis of rotating and array data, and has since developed an economical analysis interface for all major SG eddy current techniques. AIDA is now a part of AREVA’s complete eddy current examination system, which includes acquisition, analysis, data management and component integrity and engineering assessments.

AREVA uses both its own acquisition software, ARIA, as well as other vendor acquisition software programs to acquire eddy current data. In a sense, the best data analysis begins with the best data acquisition, as good analysis requires the data to be acquired with high quality – having low noise, complete extents, and accurate documentation of examination technique and component information within the data record.

The detection, analysis and reporting of indications is the main purpose of AIDA, and aspects of this analysis are discussed in depth throughout this paper. AIDA uses resolution processes with automated logic-based assessments and history comparisons to review analysis results. This ensures correct analysis reports are fed into AREVA’s data management databases. These databases are used to control and verify examination scopes of multiple techniques, such as bobbin probes, rotating probes and array probes.

Although AIDA’s primary purpose is to detect and report degradation, AIDA does much more. A number of complementary functions and features are performed by AIDA to assess component integrity, such as AVB mapping and evaluation, deposit mapping, tube identity verification, and noise measurement. The advanced AIDA platform interacts with engineering applications to efficiently provide these test results, organized in manners needed for the component assessments. AREVA’s component integrity group draws results from the eddy current exam to perform engineering assessments and to monitor and trend component conditions.

As AREVA’s eddy current software programs and engineering processes become more automated, the traditional process steps of acquisition, analysis and data management become less distinct and more integrated. Through the automation and combination of intricate processes, AREVA is composing an advanced platform of AIDA and its associated eddy current programs to dramatically increase examination capabilities and performance. With minimal human interaction, data may be automatically acquired, calibrated, verified, and analyzed with the examination results archived in databases. At the present pace of improvements, this analysis and reporting will happen in near real-time with data acquisition.

Examination Components

The main component examined with eddy current techniques by AREVA is the tubing of steam generators in nuclear power plants and systems. A steam generator tubing exam is perhaps the most complex of eddy current examinations performed, as these inspections involve a large number of tubes, a wide variety of generator designs, a complex set of damage mechanisms and reportable conditions, and rigorous set of regulatory requirements and guidelines. AREVA began development of the AIDA eddy current analysis software specifically for these complex examinations of steam generator tubing. AREVA has extensive steam generator examination experience and has used AIDA to examine all of the major types of nuclear steam generators in use today. Steam generators with a variety of designs and tubing sizes, made by all major manufacturers, and containing a wide range of damage and special interest conditions have been successfully inspected. AREVA has yet to find a steam generator design that AIDA can not analyze.

In addition to steam generator tubing exams, AREVA performs a number of specialty eddy current examinations on other balance of plant components, such as pressurizer tubes, thimble tubes, and welds.
Reactor vessel inlet pipe welds, safety systems piping welds, control rod penetration welds in reactor closure heads, and bottom mounted nozzle welds in the reactor floor are all examples of welds inspected by AREVA with a variety of eddy current techniques, including newly developed array probes developed specifically for the weld to be inspected. Due to the small quantity and specialized nature of these specialty exams, AREVA has previously employed the acquisition and analysis software of the probe vendors. AREVA is now preparing the AIDA software to also have the capability to analyze the data from these specialty weld and balance of plant exams. When ready, AIDA will be able to offer the same leading edge analysis technology developed for complex steam generator tubing inspections to other eddy current examinations.

**Examination Techniques**

For steam generator examinations, there are three main eddy current techniques: bobbin, rotating probes, and array probes. The bobbin exam is the exam of record for most steam generator examinations, and the rotating and array techniques are used as supplemental or alternate exams to provide additional information about degradation type, characteristics and size. AIDA has been improved to allow the analyst to either manually analyze or automatically analyze all three techniques. Further, the AIDA resolution process has been developed to compare the results of the various examinations to assess the degradation or condition of the component examined.

**AIDA’S ANALYSIS METHODS AND CAPABILITIES**

**Manual Analysis**

Even in an environment of increased auto-analysis, the need for manual analysis remains. A software that delivers efficient, robust manual analysis functionality is still both desired and required. During manual analysis, the analyst must view many aspects of the data acquired, viewing multiple data channels in various views to determine the condition of the component. Often, in a production environment for an examination of many components, such as the thousands of tubes in a steam generator, the analyst must perform a series of repetitive tasks.

AIDA has been designed using the best practices of the industry and ergonomic considerations to provide a way for analysts to view the data as necessary, with a minimal amount of effort. Various layouts have been designed for each examination type. User-friendly operation using human factors and ergonomics include the following considerations. The number of mouse motions, clicks and keyboard strokes have been minimized. Controls and buttons are organized and placed with the analysis process in mind. Better graphical processes provide increased manual speed capability. Reducing fatigue leads to reduced errors and better analysis results. The buttons and controls are intuitive for both novice and experienced analysts, so there is minimal (or no) software training required for experienced analysts. This allows AIDA to be easily adapted by secondary vendors worldwide. The key goal AIDA meets is that it allows analysts to focus on the data, without the distraction of thinking about how to operate the software.

**Automated Analysis**

Automated analysis is the use of a computer algorithm to detect, analyze and report indications. The advantages of automated analysis are clear. As with any automated process that replaces a manual process, automated analysis has the benefits of producing objective, consistent and fast results. The reliability of objective exam results without human error and the financial benefits of faster analysis results have lured research efforts since before AIDA even existed. The concerns for automated analysis are also typical of the concerns for any automated intelligence, in particular, how does one compensate for uncertainty? For the field of NDE, examinations are performed to eliminate uncertainty. How does one ensure there are no programming errors that would result in a miss of a significant indication? How does one ensure the detection of all degradation types, particularly flaw responses that are not well described or are in regions of signal noise and uncertainty. The varying conditions of steam generators and the variety of signals in these examinations have proven to be a challenge to automated analysis algorithms for decades. AREVA has met these challenges, first with developments and advancements in traditional automated analysis techniques, followed by recent breakthroughs in the discoveries of advanced automated analysis algorithms.
Preparation
AIDA’s automated routines are prepared for each examination using industry experience databases and site-specific historical data. Such preparation ensures that both expected and unexpected damage mechanisms will be detected. Both industry performance tests and site specific tests are used to demonstrate and qualify AIDA for examinations. In the entire history of using AIDA as an automated analysis tool, AIDA has never missed an indication on a site specific test, providing perfect site qualification testing results.

Locating
One element to AIDA’s automated success is landmarking and locating. In a steam generator exam, there are several tubing regions divided by the support structures of the steam generator, namely the tube sheets at each end of the tubing and the tube support plates in between that provide structural stability for the tubing. Various damage mechanisms occur as a relation to location and the associated structures, such as wear at supports, pitting in tubesheet sludge piles, and stress corrosion cracking at regions of tube diameter expansions. AIDA has multiple processes to locate structures in any generator type and then verify their location, to ensure proper analysis. Although steam generators have a set number of support structures, how they intersect a specific tube may be different for each of thousands of tubes in the steam generator. For this reason, AIDA has begun to use tube by tube landmark tables, which are large databases that store the description of the support locations for each individual tube.

Detection, Analysis, and Reporting
AIDA allows the user to control and customize each aspect of the analysis process: detection, analysis, and reporting. Although the word “analysis” is generically used to describe all three of these steps, there are key differences that should be noted, particularly when comparing the AIDA service to other analysis products.

In the detection step, AIDA detects signals of interest that may or may not be degradation. The very basic of methods for detection is to use a series of phase and voltage measurements from various frequencies and frequency mixes in a set of parameter-specified if-then logic-based determinations to identify potential signals of interest. Such logic-based assessments are a beginning step to mimic the thought processes of a human analyst. Many signals can be identified during this detection step, both degradation that should be reported as wells as overcalls (or false positive calls) that should not be reported. Many eddy current products have such routines, which are more accurately called data screening routines, as the data screening (or detection) process screens out possible degradation along with many other similar signals, in a similar way that panning for gold can screen out small amounts of gold in a pile of sand or rocks.

The analysis routines are what differentiate the degradation and other signals of interest from those signals that need not be considered for reporting, like picking specks of gold out from the rubble. Industry tests such as EPRI’s Automated Analysis Performance Demonstration Database (AAPDD) tests, measure both detection (how many truth calls were reported) and analysis capability (how few overcalls were reported). In both the bobbin and the array AAPDD tests, AIDA has scored well in both categories. In the recent AAPDD array test, AIDA detected 100% of the degradation (perfect detection capability, that exceeds human analyst performance) and average only 0.58 overcalls per tube (excellent analysis capability, that is similar to human analyst performance).

After analyzing all detected signals to identify the relevant indications, the abilities to adjust reporting criteria and control what is reported are essential to meeting customer expectations for an inspection. Each of AREVA’s dozens of customers have unique requirements and desires for each of hundreds of steam generators, based on regional regulations that are required by law as well as traditional practices that need to be maintained to avoid inspection transients. AIDA’s reporting requirements ensure that the degradation level that needs to be reported is reported, without reporting indications below a specified threshold of interest. AIDA can create multiple reports simultaneously from the same sets of data records, to provide results and information for different types of exams and exam scopes. In addition to reporting degradation, AIDA provides reporting capability for tube ID verification, AVB mapping, noise reporting, sludge, denting, deposit mapping, landmark verification, and more.

Convenient Automated Features
Often after the detection, analysis and reporting of indications, there are manual operations that an analyst performs on a reported degradation responses. Some of these manual steps can be subjective and/or time consuming, such as measuring an extent, or measuring several depths along an extent.
New features in development for the AIDA analysis software include automated routines that measure flaw extents and boundaries, and automated routines to perform line-by-line sizing. The extents of flaws in tubing have traditionally been measured as lengths in two axes: a circumferential extent and an axial extent. AIDA has a prototype routine which will outline a flaw boundary, providing detailed shape information, as well as the traditional axial and circumferential lengths. An example of an automatically detected flaw boundary is shown in Figure 1.

![Flaw Boundaries Automatically Identified](image1)

Once a flaw extent is determined, either manually or automatically, a measurement can be made across each data point along the flaw’s extent using the Lissajous in the opposite direction of the extent. This incremental sizing (called line by line sizing) can be performed consistently and quickly through automation. As with any automated call parameters, the extents and start and stop locations of an automated call may be manually adjusted in the database report entries.

**An Important Technical Advancement**

AREVA has recently developed three new algorithms to detect degradation signals. Each of the three algorithms is documented and proven to be an independent and separate method with different operations and results. These processes are easy to configure for a wide variety of examinations. The new algorithms are not like the traditional rule based analysis methods, but are advanced mathematical signal processing concepts, which are applied for the first time in ET SG exams. AREVA is seeking patent protection for these first-of-a kind applications.

The new algorithms represent a breakthrough ability in the field of automated analysis. Traditionally, automated routines have had difficulty detecting small indications and have had difficulty detecting degradation in regions of signal noise. As a result, small indications may go undetected, or if thresholds are set to call small indications, a large number (hundreds or even thousands) of overcalls may be made. Since automated reports are manually reviewed to eliminate the false calls and keep the real degradation signals, a large number of overcalls burdens the analysis process. AREVA’s advanced algorithms have the ability to detect small degradation responses, and to detect indications in areas of noise without making overcalls (false positive calls). In a sense, the new algorithms both detect and analyze degradation, by simply not detecting noise signals. Recall that in previously discussed definitions, detection was considered to be the finding of a potential signal of interest and that analysis was the characterizing that signal.

![Advanced Algorithm Detects And Reports Small Degradation Without Reporting Noise](image2)

An example of one of the advanced algorithms is shown in Figure 2. At the bottom of the figure is a stream of eddy current data that contains several degradation responses of varying amplitudes. In the top of the figure are the resulting detections of one of the advanced analysis processes.
One may notice that the sixth degradation response is barely noticeable, and this small noise-like response would not likely be called by a human analyst, unless the analyst knew the degradation was there and was instructed to call the signal. The small signal is not a noise response; it is a response from actual (very shallow) degradation. Also note that the advanced analysis process did not produce any false positive calls from this data. These results show that the advanced analysis process meets or exceeds the detection, analysis and reporting abilities of an experienced human analyst.

CONSIDERATIONS REGARDING AUTOMATION AND EXAMINATION PERFORMANCE

There are some discussions in the industry regarding the performance and reliability of automated analysis. Does automation produce a high enough probability of detection? How can unknown conditions be programmed for detection or evaluation? Should every call made by an automated system be manually reviewed? How can the detection and analysis performance of automated analysis systems be objectively compared? AREVA has developed AIDA to address these issues and concerns as follows.

Probability of Detection

For some manual examinations, two independent parties (or groups) of analysts are required to analyze the data, essentially analyzing the data twice. The results of the two analysis groups are reviewed by a third group of analysts called resolution analysts. These resolution analysts are also divided into two groups, and each resolution group reviews indications of potential degradation that are deleted. For US examinations, a fifth independent analyst further reviews the data. The two-party, multi-review process is designed to increase the probability of detecting (and reporting) degradation. With the advent of automated analysis, manually edited reports of automated analysis calls have taken the place of either one or both analysis parties.

AREVA has designed AIDA to be able to perform either a manual analysis or an automated analysis. With the invention of the independent analysis algorithms, the AIDA software can perform separate automated analyses for an examination. With these options, utilities may choose the level of manual analysis or automation desired to ensure a required probability of detection. AIDA could be used for dual manual analysis, single manual and single automated analysis, dual automated analysis, or any combination of these choice in addition to a third non-AIDA analysis. Using AIDA’s recent EPRI AAPDD test results of 100% detection of array data indications along with other site-specific test results allows AIDA to offer a high probability of detection with or without the addition of a manual analysis party.

What should be required for overcalls (false positive calls)

AREVA eddy current analysis processes have always required that human analysts review every call made by an automated eddy current system, and to determine the relevance of the call - whether the call should be kept or deleted. The more overcalls that an automated system makes, the greater the chance of human error occurring when keeping or deleted the indications. If overcalls are not reviewed (or more precisely, if some calls are disregarded and not manually reviewed to determine if they are overcalls), then there is a risk of not reviewing and reporting a critically important degradation response. Disregarding a set of automated calls, perhaps based upon some voltage threshold, in essence leaves part of the data un-analyzed - and not just any part of the data, but a portion of the data that is more likely to contain a significant indication than nominal tubing (since there is an indication there to begin with).

With traditional AIDA auto-analysis methods, few overcalls occur. The range of overcalls per tube that has occurred in past inspections is 0.1 to 4.0, depending upon tubing and data conditions. A typical overcall rate for present day examinations of replacement generators is 0.5 calls per tube. With the incorporation of AREVA’s advanced auto-analysis algorithms, these overcall rates may be further reduced. By having an automated analysis software with such a high analysis ability, AREVA can continue to manually review every analysis result, either with a review analyst or a resolution analyst, and leave no portion of data unanalyzed.
Detecting the Unknown

A final concern about automated software is its ability to detect a condition for which it has not been programmed. How well can automated analysis detect degradation in unexpected and unusual responses? The answer to detecting unexpected condition lies in comparing present data with past data, such as either the previous outage data or the baseline data. AREVA has developed a method of mixing the historical data with the present data to show regions of change. This change can then be assessed to determine if degradation or a condition that needs investigation is present. This application of a graphical historical comparison can “let you know what you don’t know”, and identify potentially new degradation responses.

CONCLUSION

Many parts of an analysis software program must function well and work together effectively in order to perform successful eddy current examinations. AREVA has developed the AIDA analysis software to perform multiple analysis functions, and interface with both acquisition and reporting systems. Extensive and comprehensive manual controls to operate highly customizable automation processes allow AIDA to produce accurate results in desirable formats, meeting both customer requirements and desires. AREVA’s significant investment in continuous improvements and in research of new mathematical signal processing methods have produced a world-class eddy current analysis software, with unique and advanced capabilities and functions designed to exceed industry standards.

Additional Information

Please contact AREVA for more information about AIDA, the eddy current analysis software, and how utilities benefit from this inspection service. In Europe, ASIA or Africa, please contact Joel Martens in AREVA’s Rungis, France office, at 33-01-49-78-4084 or joel.martens@areva.com. For those in the Americas or Australia, please contact Ratko Vojvodic in AREVA’s Lynchburg, VA, USA office, at 434-832-4081 or ratko.vojvodic@areva.com. Thank you for your interest in AIDA eddy current analysis.