6th CNS International Steam Generator Conference
November 8 – 11, 2009, Toronto, Ontario, Canada

DATA ANALYSIS ALGORITHMS FOR FLAW SIZING BASED ON EDDY CURRENT ROTATING PROBE EXAMINATION OF STEAM GENERATOR TUBES†

Sasan Bakhtiari and Thomas W. Elmer
Nuclear Energy Division, Argonne National Laboratory

ABSTRACT

Computer-aided data analysis tools can help improve the efficiency and reliability of flaw sizing based on nondestructive examination data. They can further help produce more consistent results, which is important for both in-service inspection applications and for engineering assessments associated with steam generator tube integrity. Results of recent investigations at Argonne on the development of various algorithms for sizing of flaws in steam generator tubes based on eddy current rotating probe data are presented. The research was carried out as part of the activities under the International Steam Generator Tube Integrity Program (ISG-TIP) sponsored by the U.S. Nuclear Regulatory Commission. A computer-aided data analysis tool has been developed for off-line processing of eddy current inspection data. The main objectives of the work have been to a) allow all data processing stages to be performed under the same user interface, b) simplify modification and testing of signal processing and data analysis scripts, and c) allow independent evaluation of viable flaw sizing algorithms. The focus of most recent studies at Argonne has been on the processing of data acquired with the +Point™ probe, which is one of the more widely used eddy current rotating probes for steam generator tube examinations in the U.S. The probe employs a directional surface riding differential coil, which helps reduce the influence of tubing artifacts and in turn helps improve the signal-to-noise ratio. Various algorithms developed under the MATLAB® environment for the conversion, segmentation, calibration, and analysis of data have been consolidated within a single user interface. Data acquired with a number of standard eddy current test equipment are automatically recognized and converted to a standard format for further processing. Because of its modular structure, the graphical user interface allows user-developed routines to be easily incorporated, modified, and tested independent of the core code, thus providing a useful research tool for development and evaluation of new signal processing and data analysis schemes. The software can be used for either manual or automated analysis of data. Algorithms for sizing of flaws using single and multiple test frequencies have also been implemented. The algorithms provide different degrees of conservatism in estimating of the flaw size. Evaluation of the results so far has been based on data collected from tubes with machined and laboratory-produced flaws. Representative test case results from these studies are presented.

1. INTRODUCTION

Reliable detection and characterization of flaws in steam generator (SG) tubes is important for the evaluation of tube structural integrity. Eddy current (EC) testing in its various forms is the primary method for in-service inspection (ISI) of SG tubes. High-speed bobbin probes are used for full-length inspection of the SG tube bundle. Intrinsic to its coil design, bobbin probe provides a single circumferentially integrated measurement at each position along the tube axis. The relatively large coverage of the coil also limits its ability to resolve closely spaced

† Work sponsored by the U.S. Nuclear Regulatory Commission, under NRC Job Code N6583.

discontinuities along the tube axis. Motorized rotating probe coils (MRPC) are routinely employed for the inspection of selected regions of the SG tube (e.g., tube sheet, support plates, and U-bend region) or as a supplementary technique for confirmation of signals detected initially by bobbin probes. Rotating probes traverse the tube with a helical motion that results in a complete scan of the tube wall. The probe head assembly may contain single or multiple surface coils that can provide complementary information. Directionally sensitive probes are used to more decisively identify the orientation of crack-like indications. One common surface-riding rotating probe design in use today consists of three coils that are integrated into a single probe head: a differential cross wound coil (referred to as +Point™), an absolute mid-frequency pancake coil, and an absolute high-frequency pancake coil. Because MRPCs in general offer the highest spatial resolution among all eddy current probe types used for field applications, they are often employed to ultimately resolve and size potential flaws. Conventional procedures for estimation of flaw size, either for ISI applications or for subsequent engineering assessments, are based primarily on manual analysis of rotating probe data. Development of computer-aided data analysis tools is a viable approach to help improve the reliability, repeatability, and efficiency of flaw sizing based on rotating probe examinations.

Manual analysis of multiple–frequency eddy current (EC) data, either for detection or for sizing of flaws, is a tedious and challenging process. Conventional data analysis methods become rather subjective when dealing with complex forms of degradation such as stress corrosion cracking (SCC). Signal distortion by interference from internal or external artifacts in the vicinity of a flaw further complicates discrimination of flaw signals from noise (any unwanted signal). Past studies involving manual estimation of the depth profile for SCC type flaws in laboratory-degraded specimens have indicated that significant variability could exist among the sizing results by different analysts, particularly when dealing with weak signals [1,2]. Software-based signal processing and data analysis techniques, when applied properly, can help reduce the influence of noise and consequently improve the signal-to-noise ratio (S/N). Computer-aided data analysis tools that employ such algorithms can increase the detection capability and the consistency of sizing results among analysts, furthermore increaseing the process efficiency that is needed for more routine application of detailed sizing procedures during field inspections.

An overview of research activities at Argonne National Laboratory (ANL) associated with computer-aided analysis of EC inspection data is presented. The overall objective has been to examine methods that could help improve the reliability of tube integrity assessments based on the nondestructive evaluation (NDE) results. The NDE results were used both to assess the capability of a particular EC inspection method for sizing of flaws and as input to mechanistic models for prediction of the structural integrity of SG tubes [3]. The main focus of these investigations was on the processing of data acquired with the +Point™ probe.

2. STRUCTURE OF DATA ANALYSIS TOOL

The general structure of a computer-aided data analysis tool for the processing of EC inspection data is discussed here. Various stand-alone MATLAB® routines developed at Argonne to allow manipulation of data collected with different EC probe types have been consolidated under a common graphical user interface (GUI) [4-7]. The routines have been updated to run under the new software structure. The algorithms for sizing of flaws have also been integrated into the GUI for analyzing of data acquired with rotating probes. More functionality has been added in terms of the user's ability to examine data at any stage of the process. This research tool can be used for both manual and automated analysis of EC inspection data.

The data analysis GUI was created in order to facilitate dynamic testing of routines without the need for reloading of data or repeating of the previous steps each time a change is made to an intermediate process. The user interface separately handles certain parts of the data processing and management, thus allowing a routine to be implemented without a detailed knowledge about the structure and handling of the data. The embedded graphical tools of the user interface allow for extended zooming and scrolling of data for more detailed manual analysis. Data may be visualized in one-, two-, or three-dimensional display formats as well as in strip-chart and Lissajous (impedance plane) plots. The display options can be further extended by incorporating other custom plots. To further assist in evaluating of algorithms, the processed data may readily be compared with the original data or with data from other test channels at any stage. Also, the action of a routine can always be reverted and the operation may be reapplied following modifications. Processed data can be saved at any point during the analysis stage. Finally, the data analysis steps can be saved into a script file and can be applied to another data file with minimal user intervention.

The most notable feature of the software is its plugin structure that facilitates more convenient implementation and testing of new user-developed routines. Its modular user interface allows functions to be manipulated independent of the main code, thus making it more immune to process errors. New plugins (i.e., MATLAB® routines) can be linked to the GUI by simply including the specified header information and placing the file in the appropriate directory. Improvements have also been made with regard to file validation and error checking, which are performed when a data file is initially loaded and when the functions are executed. More functionality has also been provided with regard to importing and exporting of data. Under the new GUI, importing of raw EC inspection data is carried out in a more transparent manner (i.e., minimal user interaction). Another important feature of the updated user interface is its scripting tool, which permits sequential application of multiple operations in an automated manner. This capability allows for efficient processing of a large number of data files that are to be analyzed using the same set of processes.

With the new plugin system, user-defined routines may be linked under the measurement, filters, and scripting menus. The functions under the Measure menu provide several standard options for the measurement of signal amplitude and phase along any arbitrary cross section of the tube. The functions under the Filters menu modify the data. They include, among other routines, various spatial and frequency domain signal processing algorithms intended primarily for improving of the signal-to-noise ratio (S/N) by reducing the level of background noise and suppressing of artifacts.

The flaw sizing algorithms refer to a number of signal processing and data analysis routines that have been assembled under the Filters menu of the GUI. These filters are applied to the EC inspection data to ultimately generate an estimate of the flaw size in a tube. Various routines developed earlier for the manipulation of data acquired with rotating probes have been refined and integrated into the GUI. With the focus of recent studies being on the +Point™ rotating probe, additional data handling capabilities have been incorporated in order to more effectively deal with data collected with that particular probe. Because of the bipolar nature of the +Point™ coil response, it is more convenient to establish separate channels for the examination of signals from discontinuities with axial and circumferential orientation. A number of examples on the analysis of +Point™ data are provided in the following sections.

2.1. Conversion and Calibration Process

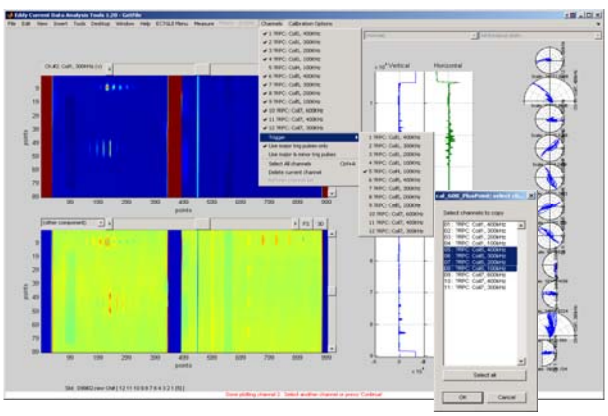
Raw data acquired with a commercial EC instrument must be first converted to a MATLAB® readable format. Description of the conversion and segmentation routines developed earlier at ANL has been provided in other reports [5]. In brief, the file header information is first read in order to retrieve the minimum necessary information regarding the type of data, the number of channels, and the test frequencies used for inspection of the SG tube. Based on that information the data is converted into proper format for further manipulation with the data analysis tool.

Data conversion plugins were created for use under the new data analysis GUI. The new software structure allowed implementation of algorithms for importing of other types of data that could not be readily processed before. Raw EC inspection data in a number of different formats can now be imported directly from the main user interface. New algorithms have also been developed that automatically detect the trigger channel for rotating probes during the file conversion process. Data file recognition is based in part on the file's extension and the conversion process is carried out in a semitransparent manner. The file types that are currently recognized include those acquired with certain commercial EC test equipment (e.g., Miz-18, Miz-30 and Miz-70 from Zetec, Inc.) as well as text, Excel™, and LabView™ files. New scripts may be added in the future for recognition of other types of data file. Upon completion of the conversion process the data is automatically saved in the current directory with the same filename but with a different file extension to facilitate re-loading in the future. Data at this initial stage can be segmented and a subset of the original channels could be selected for further analysis in order to reduce the amount of data carried through the following stages.

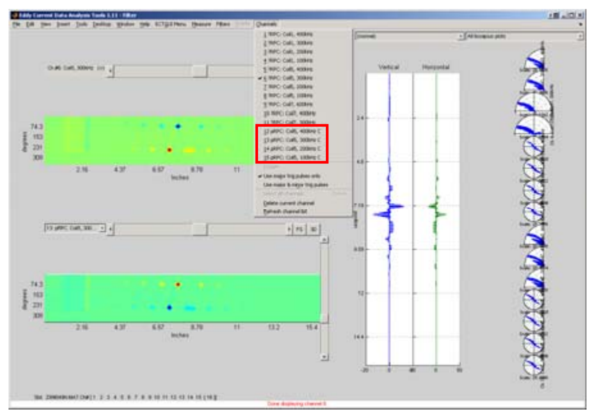
Uniform calibration of EC inspection data is essential for obtaining consistent data analysis results. The calibration procedure in general involves normalizing of the amplitude and adjusting of the phase angle of data based on signals from known flaws in a calibration standard tube. The calibration process for rotating probe data involves a number of common steps that include coil alignment, amplitude normalization, phase adjustment, and spatial scaling of data. Selected channels may be copied, rotated, and appended to the original channel list. This option was added to specifically deal with data acquired with the +Point™ directional probe for which axial and circumferential discontinuities in a tube exhibit opposite polarity. Options to resample the data and append channels to the current list are also provided under the GUI as part of the calibration process. Coil alignment is performed when more than one coil is detected from the channel configuration file. Aligning of coils allows comparison of the responses of different coils from the same location on the tube. Spatial scaling of data in the axial direction is based on user-defined spacing between known indications and circumferential scaling is done based on the diameter of the tube. Upon completion of the calibration process, the calibration values are stored for subsequent application to other data files.

An example of rotating probe data calibration following the processes described above is shown in Fig. 1. Initial loading of raw EC inspection data from two in-line calibration standard tubes is displayed in Fig. 1(a). Also shown on this figure is the dialog box for selecting the channels to append to the original channel list. Segmented and calibrated data is displayed in Fig. 1(b). The Channels pull-down menu shows the added process channels (marked on the menu).

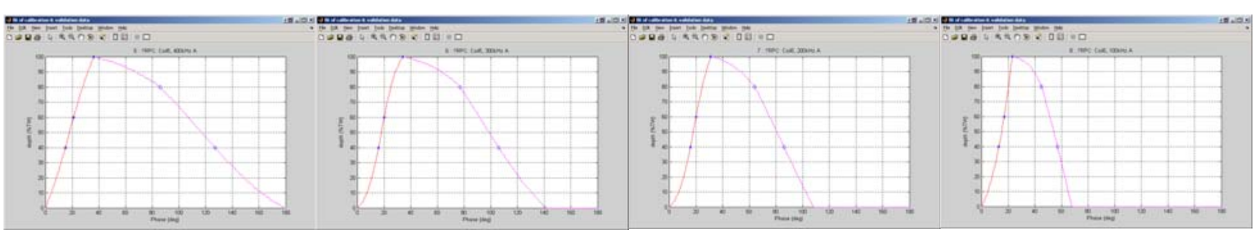
Following the initial calibration stage, phase- or amplitude-based calibration curves may be generated for use by other algorithms for flaw sizing. The function can be used to simultaneously create calibration curves for all or a subset of channels. Signals from known manufactured flaws in a calibration standard tube are generally used for this. The information provided by the user includes the origin of flaws (OD, ID, or both), the type of calibration curve (phase or amplitude), and the measurement method for the signal amplitude and phase. Following the selection of signal locations from the calibration standard tube, the curves are sequentially generated and displayed, and the calibration data is stored in a user defined file for subsequent applications. Calibration curves may be generated simultaneously for all the available channels. An example of phase-based calibration curves generated for the +Point^{TM} coil channels of a three-coil rotating probe at 400 kHz, 300 kHz, 200 kHz, and 100 kHz frequencies is shown in Fig. 1(c). Each depth-versus-phase curve in this example was generated by using a three-point piece-wise polynomial fit for the ID and the OD flaws. Interpolation through a larger number of data points could produce a more accurate calibration curve.



(a)



(b)



(c)

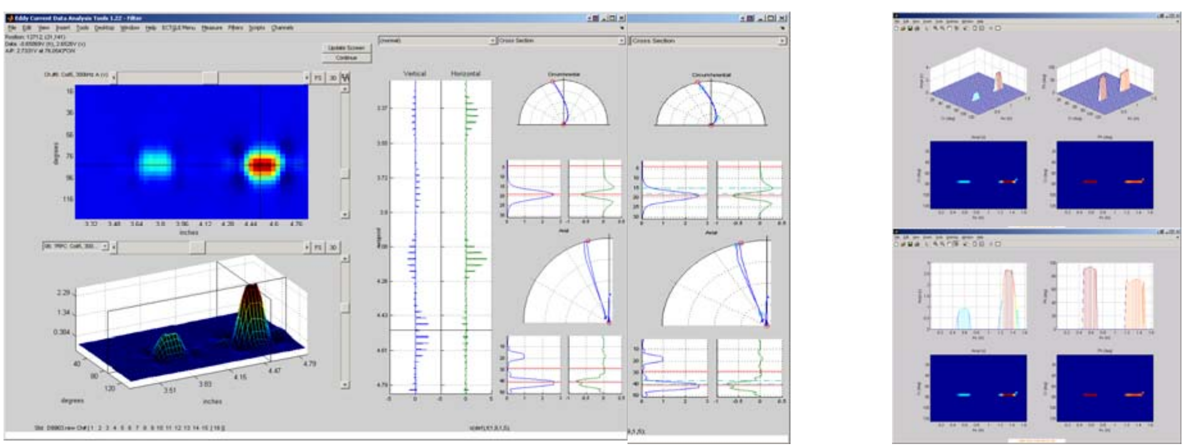
Figure 1 Representative display of different stages of data calibration process performed directly from the main GUI. Shown here are the (a) raw and (b) calibrated data for two in-line calibration standard tubes. Also shown are (c) the phase-based calibration curves generated simultaneously for all +Point^{TM} coil channels.

2.2. Data Analysis Tools

2.2.1. Measurement Routines

The measurement routines include algorithms for standard measurement of EC signals and for creating and applying of multiple calibration curves for estimation of flaw depth. Standard measurement algorithms duplicate the methods used by commercial data analysis software for measuring the amplitude and phase of the EC signals. Once the data is loaded, the graphical tools from the GUI may be used to make measurements of the amplitude and phase of a signal at any arbitrary position along the tube.

These functions permit close examination of the data following each operation. The measurements are performed simultaneously on all the available channels and the results are displayed in the command window. Measurements may be made over discrete locations along the tube or successively along a line using the scroll buttons of the two-dimensional display panels. Flaw depth profiles may be generated by applying previously established calibration curves. Alternatively, measurements could be made over a selected area of the tube in an automated manner. A peak detection algorithm that may be called from the measurement menu was developed for this purpose. The routine searches through the user-selected patch of data using a fixed-size kernel in order to locate and measure relevant signals. The default size of the measurement kernel is determined automatically based on the acquisition sampling rate and the tube diameter. An example of signal measurements made from the GUI using the two methods described above is depicted in Fig. 2. The image display shows a segment of data from a calibration standard tube containing two axial OD notches. The analysis results here are based on the +Point™ probe response from the 300 kHz test frequency. Measurement of the signal



(a) (b)

Figure 2 Representative graphics associated with the use of functions under the measurement menu. Shown here are (a) manual measurement of signal amplitude and phase based on peak-to-peak and maximum rate of change and (b) automated measurement of flaw signals over the same data segment. The data segment displayed in the GUI includes a 60% TW and an 80% TW axial EDM notch from a calibration standard tube detected with a +Point™ probe at 300 kHz.

corresponding to a single hit along the flaw length is shown in Fig. 2(a). The Lissajous displays on the left and right hand panes respectively show the peak-to-peak and the maximum rate of change measurements along the selected cross section for the signal amplitude and phase. Automated measurement over the entire data segment is displayed in Fig. 2(b). A separate display window shows the detected amplitude and phase values using the default value for the threshold. The estimated lengths of both indications are consistent with the 0.25-in. (6.35-mm) nominal length of the axial notches. The isometric and cross sectional plots of the same data are shown in different display panels.

2.2.2. Filter Routines

Various signal processing and data analysis algorithms, generally referred to here as filters, currently include algorithms for pre-processing, detection, identification, and sizing of indications. The pre-processing routines consist of spatial and frequency domain filters intended primarily for suppression of noise or unwanted signals in general. Other routines assembled in the Filters directory include peak detection, rule-based identification, outlining of potential indications, and regression algorithms for sizing. The majority of the filters are applicable both to spatially one- dimensional and two-dimensional data. Certain routines, however, are applicable only to spatially two-dimensional data. Default filter parameters can be adjusted by using the dialog boxes at the beginning of the process.

Although filter routines function in a similar manner as measurement routines, they differ in that filter operations modify the data. Furthermore, each time a filter is applied to the data the input parameters are stored and may be accessed by scripting routines at a later stage. When filters are called, the process stores the data in its current state. The Undo function may then be used repeatedly to recover the original data. The undo function is particularly useful for testing of new algorithms and for the evaluation of data analysis methods.

Proper evaluation of EC inspection techniques and data analysis methods relies heavily on the availability of a suitable database. A viable approach to expanding of an NDE database with limited number of samples is to make use of the superposition principle. Algorithms developed earlier for superimposing of EC signals have been further refined and linked under the measurement and the filter menu. This tool can be used to simulate the response of an EC probe as a result of the influence of artifacts on nearby flaw signals or the interaction of closely spaced signals in general. Simulated data created in this manner may then be used to better evaluate the ability of signal processing and data analysis algorithms to detect and characterize flaws.

2.2.3. Flaw Sizing Algorithms

The flaw sizing algorithms for rotating probes consist of a number of routines that perform various stages of the data analysis process. The common data manipulation stages consist of pre-processing, detection, identification, and sizing of indications. Post-processing of data prior to final estimation of the flaw size may also be selectively applied. This step is typically carried out to help restore data points that might have been corrupted by earlier stages of data manipulation.

Pre-processing of data is initially performed to help suppress the influence of unwanted signals and background noise. Both spatial and frequency domain filters have been developed to help improve the signal-to-noise ratio (S/N). Selection of an appropriate type of filter will depend on the nature of unwanted signals. In general, a deterministic rotating probe response from artifacts such as TSPs is more effectively suppressed by using spatial domain filters. The types of noise with specific frequency spectrum are often suppressed more effectively by using frequency domain filters. Other signal suppression techniques such as least-squares-based multi-frequency mix algorithms and spectral decomposition algorithms have also been incorporated into the data analysis tool and may be used on an application-specific basis. Reduction of random background noise, either associated with the instrument's electronics or with slight trigger-related misalignments, may also be achieved by smoothing of data. Polynomial fitting algorithms optimized for typical EC inspection data are currently used for this purpose. The routines automatically calculate as the default values the operating kernel size and the polynomial order based on the rate at which the data was sampled. The option, however, is provided to adjust the default values as necessary. It is worth noting that any filtering process is expected to influence the signal amplitude and phase to a certain degree. The default values for the filter parameters are generally set such that they provide optimal tradeoff between improving the S/N and distorting the probe response. Thus, a viable approach to evaluating the influence of filter parameters on signals in the tube data being analyzed is to first apply the identical processes to the calibration standard tube.

The detection routine employs a threshold-based algorithm that first partitions the data into a number of smaller regions. The data is initially subdivided along the lines of minimum variance that delineate the regions of interest (ROIs) for subsequent processing. The number of data segments generated in this manner may not always represent the minimum number of ROIs containing relevant signals. Various algorithms were examined for partitioning of the data into minimum number of ROIs with relevant indications. Reduction of the original number of ROIs was achieved by linking of the segments with baseline data to adjacent segments that contain signals above a threshold.

The detection process employs a search routine that locates and measures all the flaw-like signals along the orthogonal directions over each ROI. The operation can be performed over the entire EC inspection data from a tube or over a user-defined segment. The peak detection routine provides the option to select the type of measurement for the signal amplitude and phase. The default measurement type is set to the peak-to-peak value. The threshold-based detection algorithm also takes into account the signal shape in order to separate the potential flaw signals from artifacts. Both absolute and relative (to the peak signal amplitude) thresholds are used for the detection of signals within each ROI.

Identification of relevant flaw signals from tubing artifacts is done by employing a rule-based algorithm. A set of predetermined conditions are used to decide whether a signal should be kept or eliminated based on its origin and its general characteristics. The bounding values are determined based on the amplitude and phase relationships among different test frequencies for known signals from a calibration standard tube. In addition to the general rules, empirical rules are also included in that set. Although the coefficients that set the bounds for the acceptable range of signal variation may be adjusted for specific test conditions, the default values are generic and are intended to apply to a wide range of test conditions. Information from a minimum of two channels, typically consisting of a primary and an auxiliary test frequency, is needed for this stage of the process. The use of a larger number of test frequencies, however, is expected to improve the ability to identify the flaw signals.

Post processing operations are selectively applied to recover the data points that might have been corrupted by the previous operations. A subset of filters used for pre-processing of data is typically used for post-processing operations. Polynomial interpolation is typically used for this purpose. The interpolation may be carried out in number of directions including axial, circumferential, diagonal, or in a semi-circular pattern. Morphological operations may also be employed for prost processing of data. The erosion and dilation algorithms have been included in a single routine under the Filters menu.

The final estimate of the flaw size in a tube can be generated by using the data from either a single channel or from multiple channels. Different options are currently available for calculating the flaw depth based on the signal amplitude, phase, or both pieces of information. A multiple linear regression algorithm is employed for calculation of depth from multiple test frequency data. A set of dynamic functions have been implemented which convert the processed data into the final estimate of the flaw depth. These algorithms currently allow calculation of the flaw depth based on the available data from a single test frequency or from multiple test frequencies. Alternate methods using the amplitude, phase, or the combined amplitude and phase (hybrid) information can currently be applied to estimate the flaw depth. The option is also provided to estimate the depth of an indication based on the minimum, maximum, mean, or the median of all the values predicted by the different test frequencies. For multi-frequency inspections, this option allows for different degrees of conservatism when estimating the depth an indication. This approach may be particularly useful for sizing of low-amplitude indications for which significant variation could exist among the predicted depths at different test frequencies or by different coils.

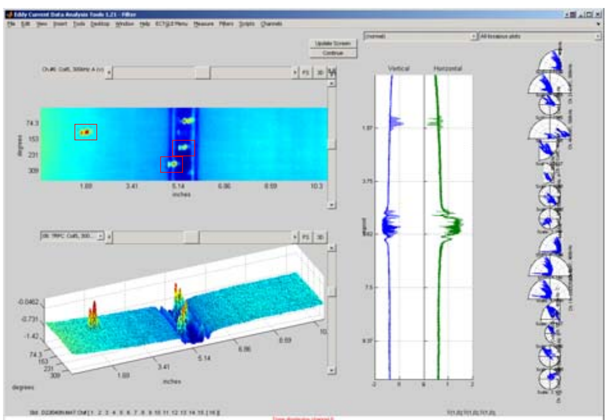
2.2.4. Scripting Tool

Functions are provided in the GUI for automatic creation of MATLAB® scripts. Scripts allow filters to be applied sequentially to the data. The scripting tool is particularly useful for efficient processing of a number of data files that are to be manipulated in a similar manner. New data files may be analyzed quickly once the processing steps have been determined. The software structure permits an arbitrary number of filters to be included in the scripts file. A script can be saved at any time during the data analysis process using the embedded function from the Scripts menu. The script is saved as a standard MATLAB® text file (m-file) and may be later modified manually if necessary.

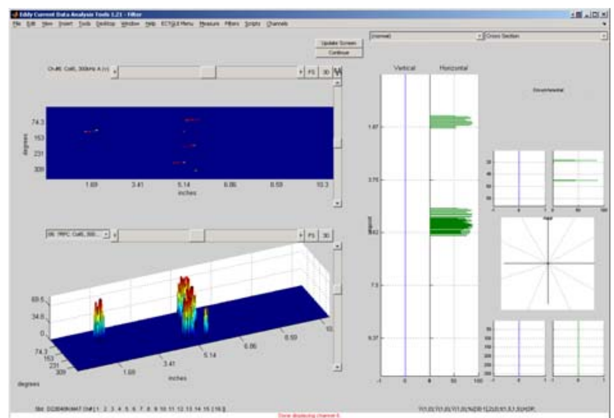
3. TEST CASE RESULTS ON FLAW SIZING

Eddy current rotating probe data was used to estimate the size of flaws in a number of mock-up tube specimens. Data on all the tube sections was collected with a three-coil rotating probe, which employs a mid-range 0.115-in. (~3-mm) -diameter pancake coil, a +Point™ coil, and a high-frequency 0.080-in. (~2-mm) -diameter pancake coil, with all the coils embedded in a single probe head assembly. The analysis results presented here pertain only to the +Point™ data. The database of tubes used in these investigations included both axial and circumferential SCCs, with the majority of the flaws being OD initiated. The specimens contained either single or multiple indications located in one particular region of the tube (i.e., either free-span or TSP). In order to better evaluate the ability of the algorithms to detect and size flaws over the entire length of a tube, the original data set was augmented with simulated data. The data superposition tool under the GUI was used to compensate for the lack of specimens with discrete indications located at different regions of the tube.

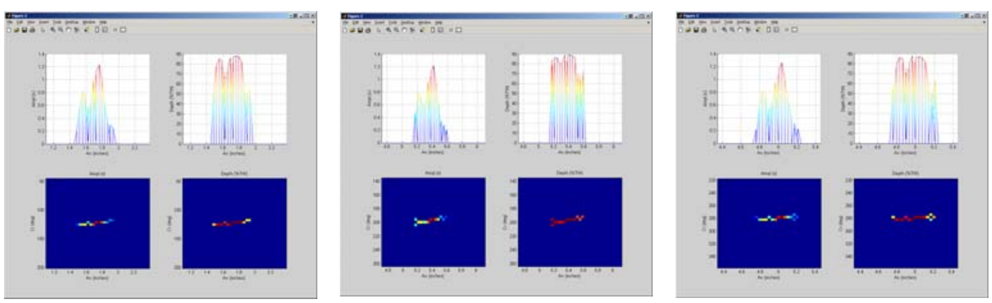
An example is presented next on sizing indications over the entire length of tube based on rotating probe data. Figure 3(a) shows the data collected from a mockup tube section containing multiple indications at a dented TSP region. A flaw signal extracted from another tube was inserted at three different locations over the tube. Fig. 3(b) shows the results following the pre-processing, detection and rule-based identification stage. The sizing result displayed by the GUI over the entire tube length is shown in Fig. 3(c). The data in this case indicates that in addition to the original signals in the TSP region of the tube, all three simulated flaw signals are also detected and sized. Comparison of the amplitude and depth profiles of the SCC signal added to three different locations suggests good agreement between the sizing results. The results in this case also indicate the effectiveness of the background suppression routines to both eliminate unwanted signals and to minimally perturb the flaw signal.



(a)

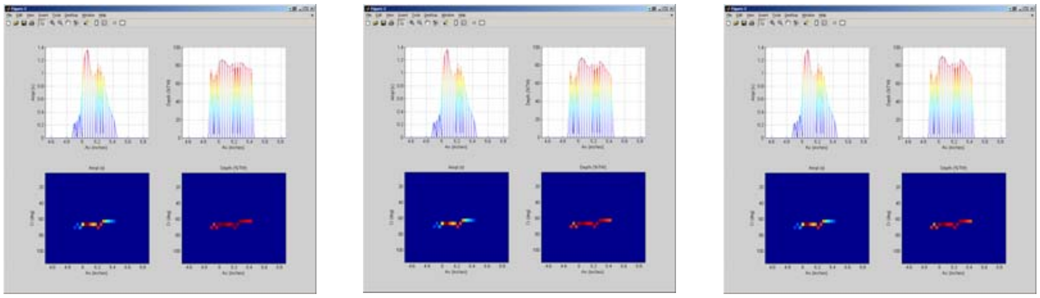


(b)



(c)

Figure 3 (a) Example of superposition of EC inspection data collected from two separate tube sections with the inserted signals delineated on the image. (b) An intermediate stage of the process following the detection of flaw signals over the entire length of tube section. (c) Single frequency estimates of flaw size in the free-span and TSP region of the tube.



(a) (b) (c)

Figure 4 Single and multiple frequency flaw sizing results for the same tube shown in Fig. 3. These results use the phase information from (a) 300 kHz, (b) 400 and 300 kHz, and (c) 400, 300, and 200 kHz channels. The estimated depth profiles for the dominant flaw in the TSP region suggest close agreement between the three sizing results.

As described earlier, dynamic functions referred to here as Depth Profilers allow calculation of the flaw depth based on a number of different methods. These algorithms currently allow calculation of the flaw depth based on the available data from a single or multiple test frequencies. Alternate methods using the amplitude, phase, or the hybrid sizing can currently be applied. A representative test case is presented on comparison of flaw sizing results obtained using data from a single frequency with that obtained using multiple test frequencies.

Figure 4 displays the single- and multiple-frequency sizing results for one of the indications in the same tube. The sizing results were generated by using the data from the 200 kHz, 300 kHz and 400 kHz test frequencies. Comparison of the depth profiles for the dominant flaw suggests good agreement among the three sizing methods. In all cases here, the flaw is predicted to have a maximum depth of slightly less than 90% TW. It should be noted, however, that more variation among the sizing results are expected for more complex flaws and for low-amplitude signals.

4. CONCLUSIONS

An overview of research activities at Argonne associated with computer-aided analysis of EC inspection data was provided. The results of efforts on the development and integration of various algorithms for sizing flaws based on eddy current rotating probe data have been discussed. The main focus of these investigations was on the processing of data acquired with the +Point^{TM} probe. It should be noted, however, that many of the processes described in this report are applicable to data acquired with other probe types. The overall structure of a software-based tool, developed under the MATLAB® environment, for the processing of data acquired with different EC probe types was described. The three main stages of the process were discussed. The main algorithms for sizing of flaws were also discussed. Representative cases have been provided on estimation of flaw size based on alternative methods. The examples demonstrate the options available for the processing of data over a selected region or the entire length of the tube. Other functions including those implemented for superposition of data and for exporting of data in standard formats were also discussed. A viable approach, not evaluated under this work, is to incorporate the available information from different coils of a multi-coil rotating probe. EC inspection data from different coils could plausibly be used to implement more elaborate expert system algorithms for improved detection and in multivariate analysis routines for estimation of flaw depth.

5. REFERENCES

[1] D. S. Kupperman, S. Bakhtiari, W. J. Shack, J. Y. Park, and S. Majumdar, “Evaluation of Eddy Current Reliability from Steam Generator Mock–Up Round-robin,” NUREG/CR6785; ANL–01/22, Nov. 2001.

[2] D. S. Kupperman, S. Bakhtiari, W. J. Shack, J. Y. Park, and S. Majumdar, “Eddy Current Reliability Results from the Steam Generator Mock–up Analysis Round–Robin: Revision 1,” NUREG/CR–6791, 2008.

[3] S. Majumdar, C.B. Bahn, Ken Kasza, and S. Bakhtiari, “Technical Letter Report on Validation of the Equivalent Rectangular Crack Method,” NRC Letter Report, submitted for publication, Aug. 2008.

[4] S. Bakhtiari and D. S. Kupperman, "Advanced NDE for Steam Generator Tubing," NUREG/CR–6638 (ANL–99/09), Jan. 2000.

[5] S. Bakhtiari, J.Y. Park, D.S. Kupperman, S. Majumdar, and W, J, Shack, “Advanced Nondestructive Evaluation for Steam Generator Tubing,” NUREG/CR–6746 (ANL–01/21), Sept. 2001.

[6] S. Bakhtiari, J.Y. Park, D.S. Kupperman, S. Majumdar, and W. J. Shack, “Final Report on Advanced Nondestructive Evaluation for Steam Generator Tubing for the Second International Steam Generator Tube Integrity Program,” NUREG/CR–6814 (ANL–03/4), July 2003.

[7] D. S. Kupperman, J. Y. Park, S. Majumdar, S. Bakhtiari, K. Kasza and W. J. Shack, “Non-destructive and Failure Evaluation of Tubing from a Retired Steam Generator,” NUREG/CR-6924, ANL-06/48, March 2007.