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E. Shchukis / V. Lunin/ M. Zelenskiy

# Flaw signals classification and parameterization in steam generator heat exchanger tubes

Significant corrosive degradation of steam generator (SG) tubes is currently discovered on a number of WWER NPP power units. Vast majority of tubes are removed from service not by leakage detection as before, but according to the results of eddy-current testing (ECT) [1]. ECT results are becoming the basis for decision-making concerning SG service life and necessary replacement. Furthermore, operating experience has shown that it is impossible to timely discover the activation of corrosion process in SG without ECT. Such conditions highly increase the demands for the quality of testing, as well as for the processing and interpretation of its results. Signal interpretation is conducted by specially qualified analysts on the basis of theoretical knowledge, training and practical experience. However, data analysis in multifrequency ECT involves significant dificulties due to the presence of numerous interfering parameters and noise levels. Automatical data analysis algorithms are created in order to overcome those dificulties and to solve the problem of detection, classification and parameterization of discovered responses.

The paper suggests a method for isolating the areas of interest by means of discrete wavelet transform and a fuzzy-logic based decision-making algorithm. Flaw classification is based on Mamdani fuzzy interference algorithm and flaw parametrisation is conducted by means of Adaptive-Network-Based Fuzzy Inference System (ANFIS). Basic stages of eddy-current signal processing: pre-processing, calibration, filtration, isolating areas of interest, flaw detection, flaw parameterization and classification.

During a field inspection of heat exchanger tubes an eddy-current probe passes sequentially through inspected, calibration (with reference flaws) and, optionally, guide tubes. The main goal of the pre-processing unit is to determine the signal fragment with diagnostically significant information (inspected area signal) and the fragment from calibration tube.

Raw data calibration involves conversion from ADC samples to phisical values (mV) and signal scaling in order to bring flaw signal phases on calibration tubes in accordance with reference. Filtration unit is used to tune-out basic interference. That is performed by means of median filter, Butterworth filter and adaptive Wiener filter, as described in previous research [2-4]. The isolation of diagnostically significant areas is implemented via discrete wavelet expansion and thresholding [2]. First order Daubechies-wavelet was selected to isolate structural elements, as the form of the mother wavelet coincides with an absolute plate signal on the frequency of 60 kHz. Algorithm verification on all available SG tubing signals demonstrated good results – all signal fragmets with support plates were framed. Flaw signals were isolated by means of first order coiflet. In accordance with Mallat algorithm third wavelet coefficient corresponds with normalized frequency [pi/8 pi/4]. Flaw signal Fourier transform is located in the same frequency domain. Therefore the third wavelet coefficient was selected to isolate flaw signal fragment.

The determination of whether the signal fragment corresponds to a flaw or not is conducted based on a set of rules composed after database analysis of model and experimental signals.

The data is currently processed with Mamdani and Sugeno fuzzy interference algorithms. Flaws are classified by location as external, internal and through and by depth as dangerous, not dangerous and critical.
Normally, in the process of flaw classification signal phase on different frequencies is taken as reference. This research suggests phase difference as a more stable reference: 60 kHz – 130 kHz, 130 kHz – 280 kHz, 60 kHz – 280 kHz. Thus the classifier has three inputs for signal criteria and one output which specifies the class of the current flaw.
Suggested algorithms were adjusted and verified on a database of flaw models from finite element model [5] and experimental signals. Flaw classification error for the entire database is 2.5%.
Fuzzy-logic application results were compared to the research of a neural-network classifier [6]. Result analysis leads to a conslusion that fuzzy-logic based algorithms are more preferable for flaw classification. Flaw parameterization can be conducted by neural networks as well as fuzzy logic.

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