EDDYONE AUTOMATED ANALYSIS OF PWR/WWER STEAM GENERATOR TUBES EDDY CURRENT DATA

Dr.sc. Berislav Nadinic dipl.ing.
R&D Department Manager
INETEC Institute for Nuclear Technology
Dolenica 28, 10000 Zagreb, Croatia

Mr. sc. Zvonimir Vanjak dipl.ing.
Faculty of Electrical Engineering and Computing
Unska 3, 10000 Zagreb, Croatia

ABSTRACT

INETEC Institute for Nuclear Technology developed software package called EddyOne which has option of automated analysis of bobbin coil eddy current data. During its development and on site use, many valuable lessons were learned which are described in this article. In accordance with previous, the following topics are covered:

1. General requirements for automated analysis of bobbin coil eddy current data
2. Main approaches to automated analysis
3. Field experience with EddyOne software
4. Development directions
5. Automated analysis software qualification
6. Conclusions

It has to be pointed out that our field experience was collected also on WWER steam generators what is for now unique experience.

1. INTRODUCTION

Automated analysis of eddy current data has been used for more than decade (first use was in 1988.) in PWR NPP to provide rapid detection of degradation in steam generator tubing. The up to now results were very different. Some users claim that it is completely contra productive because of numerous overcalls, some users claim it is good for some type of indications and some users claim it is excellent for most indications. Such conclusions are result of:

- Quality of eddy current data
- User theoretical knowledge of EC method
- User intellectual skills
- Characteristics of Automated analysis computer program.

Nevertheless, the use of automate analysis software is growing because of following reasons:

- Cost savings by reducing manpower and equipment requirement needs,
- Schedule savings by:
  - reducing impact of data analyst shortages during peak outage periods
  - providing faster data analysis results
- Reliability improvements by providing consistent, repeatable and accurate inspection results.

On WWER steam generators Automated analysis is widely used only by INETEC using EddyOne software package.

2. MAIN APPROACHES TO AUTOMATED ANALYSIS

Automated analysis of eddy current data is achieved by systems incorporating software that allows the transformation of eddy current data into an analyzed output.
These systems are typically applied in one of the following ways:

1. Detection only mode: in which the software detects signals and the analyst applies manual analysis to the signal to decide whether to accept or reject the signal.
2. Interactive mode: in which the software detects and analyzes the signals and the analyst reviews the signals identified by the software and compares them with their own analysis of the signals before the results are accepted or rejected.
3. Fully automated mode: in which the software detects and analyzes the signals and the analysis results are accepted with no human intervention.

From the standpoint of applied algorithms the Automated analysis can be based on the following:

1. Simple channel data screening algorithms

   Simple channels data screening means that particular number of channels are screened using threshold values for signal amplitude (Voltage) and signal phase. If threshold values are reached program call the indication. Channels can be raw or processed (mixed or filtered) to obtain best results.

2. Data screening algorithms associated with logical rules which connect screening channels

   This type of algorithms allows users to make logical correlations of their choice between screen channels. Such logical correlations can be AND, OR, NOT. It means that for example expression CH1 AND CH3 in EddyOne program will mean that the program will call indication if on screening channel No.1 thresholds are reached, as well as, thresholds on channel No 3. Such approach allows very flexible handling of indication calling logic.

3. Advanced algorithms based on principles of artificial intelligence with possibility of learning

   Advanced algorithms which are the most suitable for use in eddy current analysis (great speed, easy self learning applicability on all type of indications), are algorithms based on neural network logic. That is the reason why INETEC decide to introduce neural networks logic for solving problems in automated data analysis.

3. PARAMETERS INFLUENCED AUTOMATED ANALYSIS

Some parameters of program for data analyses have essential influence on automated analysis results. These parameters are:

- **Algorithm for determination of landmark location**
  Automated analysis is looking for particular types of indications on particular locations along tube. It means that is essential for automated analysis that it knows where it is in the tube at every moment. This is a function of landmark location algorithm which recognizes tube support plates, tubesheet, anti vibration bars and other structures which are normally used for location definition in steam generators. For such purpose INETEC also developed two algorithms; threshold one and one based on neural network principles. See Figures 1, 2 and 3.

Figure 1. Example of results obtained by EddyOne landmark location threshold algorithm (Krsko NPP)

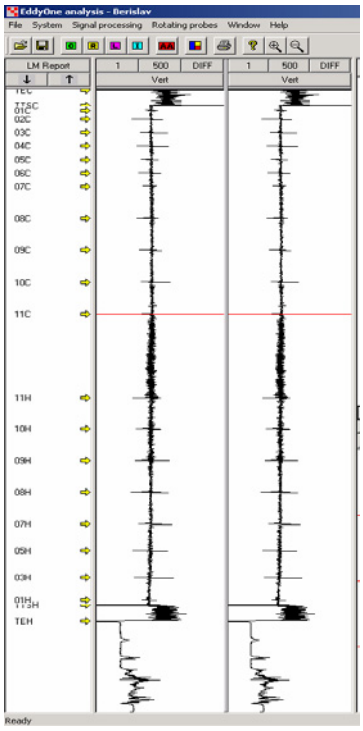


Figure 2. EddyOne setup screens for Landmark autolocate parameters based on threshold algorithm

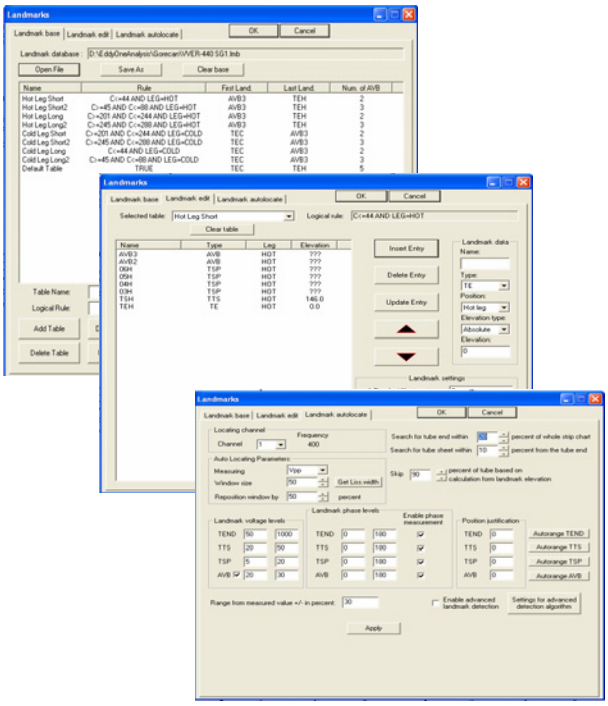
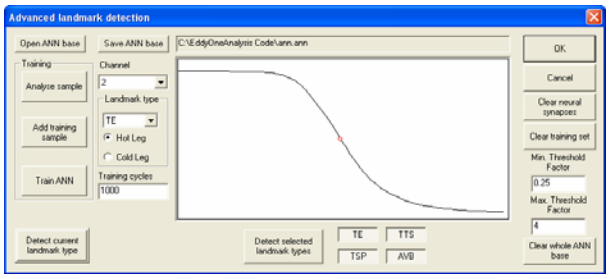
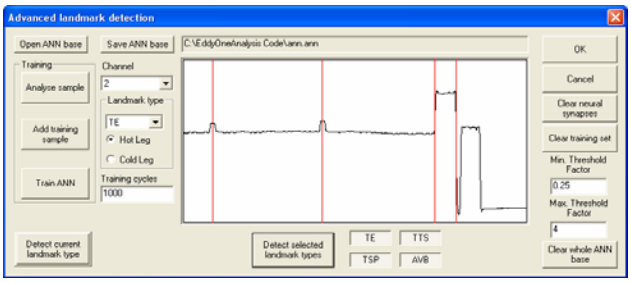


Figure 3. EddyOne setup screen for Landmark autolocate parameters based on neural network algorithm

a) giving a representative sample



b) response of neural network algorithm just to inform analysts about quality of learning process



- **Width of the screening window**
  Width of screening window is extremely important parameter in automated analysis. All measurements of signals are performed inside such window which is moving through tube signal from one place of interest to another, see Figure 4. If the width of signal is too narrow (see example on Figure 5, source Reference 1.) automated analysis can missed big indications, or in the case if the window is too open, automated analysis can missed small indications. So, the opening of screening window has to be well balanced for situations we are expecting on some particular field data, or the size of screening window has to be variable. EddyOne software can work on the same screening channel with various sizes (openings) of screening window, or it can work in so called dynamic mode (see Figure 6 which shows basic principle of dynamic mode). The problems of work in dynamic mode is the speed of automated analysis program which is at least slower for the level of magnitude then fix window sized screening.

- **Speed of screening window**
  Usually ideal speed of screening window is speed of one data point between two successive measurements. In some cases to speed up the process of automated analysis, speed can change on 2 or more data points between two successive measurements. In some cases where very small indications are of interest this can be dangerous because of risk to avoid some of them.

- **Auto-centering algorithm**
  When automated analysis find indications in accordance with all screening parameters and analysis logic it has to make appropriate centering on found signal. For such centering analysis program has to have adequate algorithm. Effects of use of EddyOne Auto-centering algorithm are shown on Figures 7 (without) and Figure 8 (with). Also for signals with not distinctive end from one side, phase limit has to exist in the scope of Auto-centering algorithm. For better understanding see Figure 9.

Figure 4. Screening window

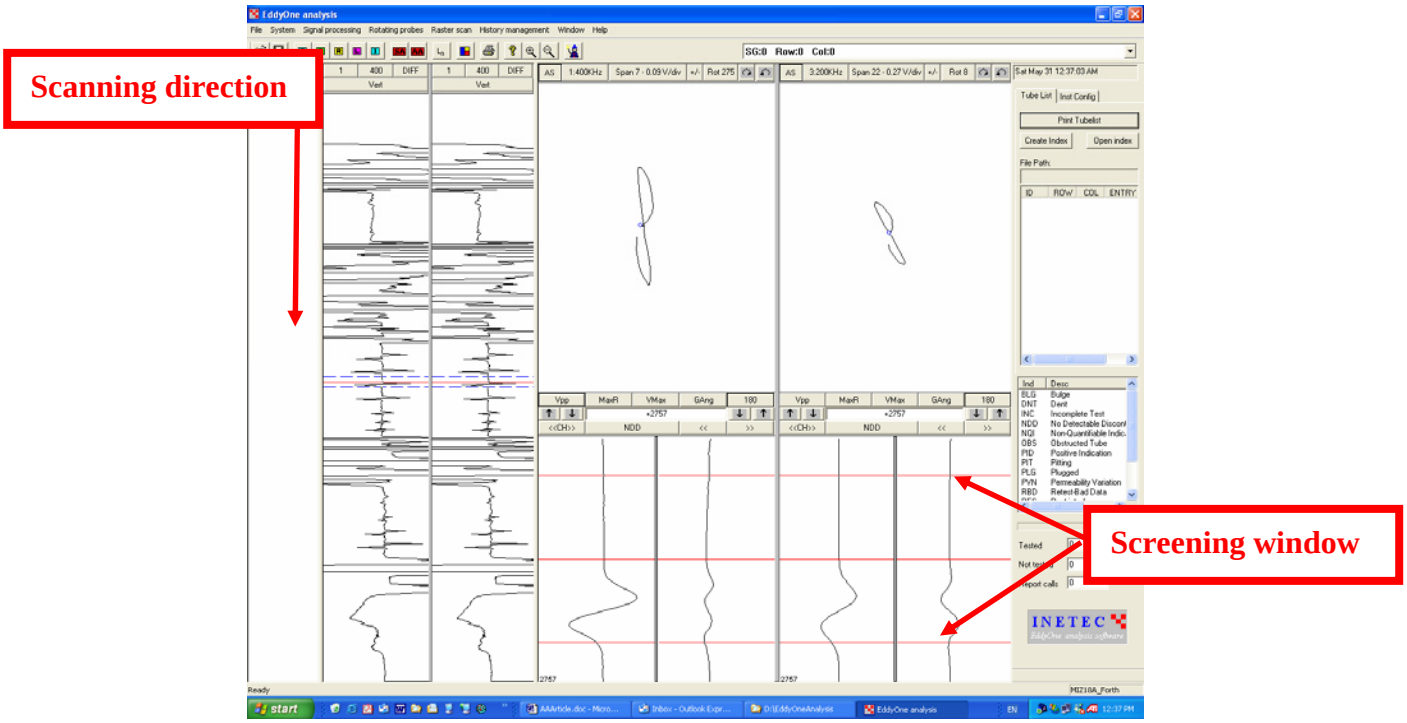


Figure 5. Example of missing indication using too narrow window (Reference 1.)

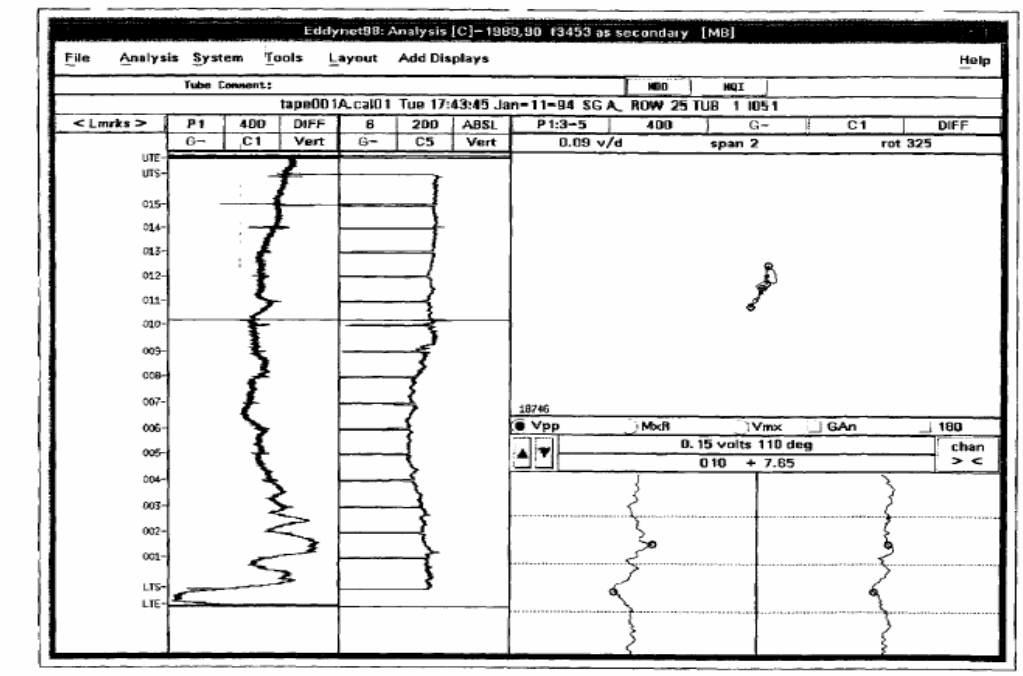


Figure 6. Dynamic mode of screening window

a) Screening with fix window

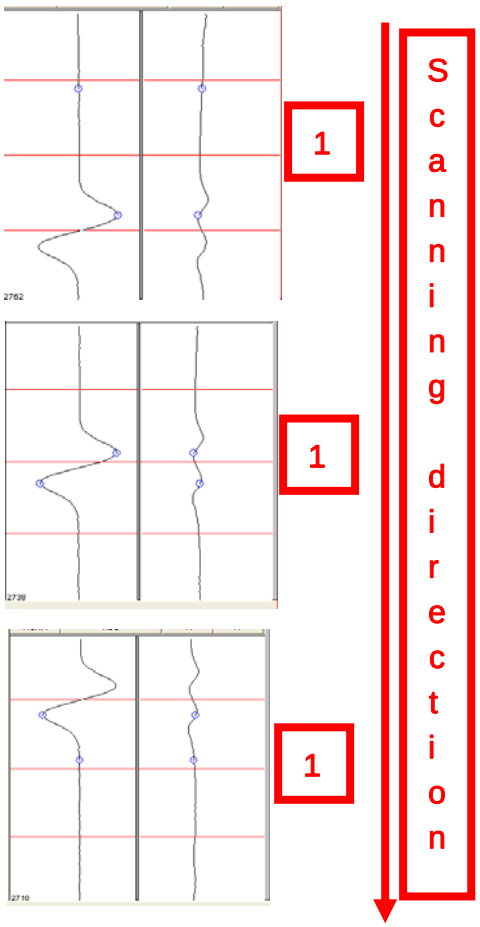


Figure 7. Without AutoCentering- first hit

b) Screening in dynamic mode

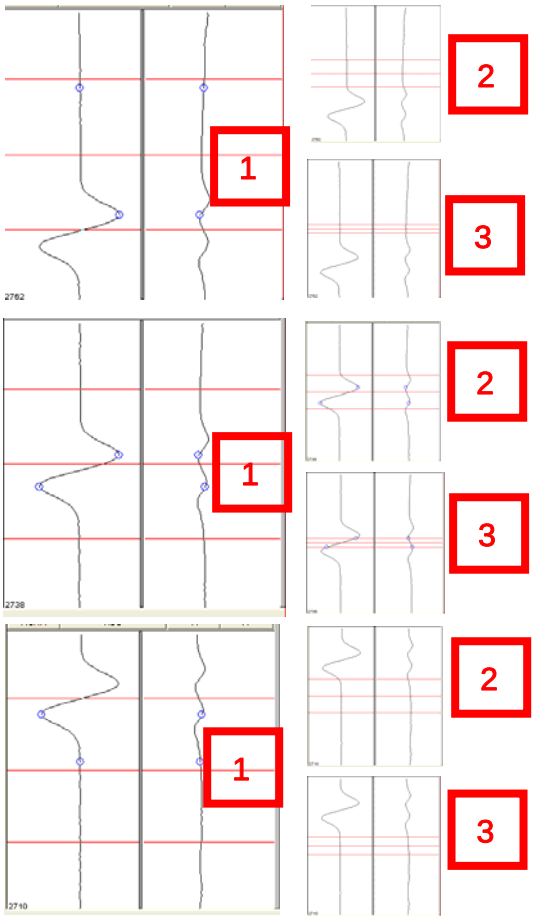
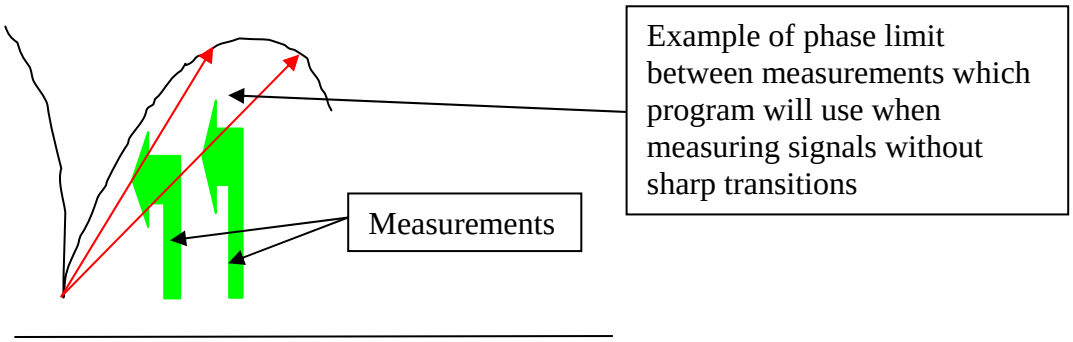


Figure 8. With AutoCentering - first hit

Figure 9. Phase limit during measurement process

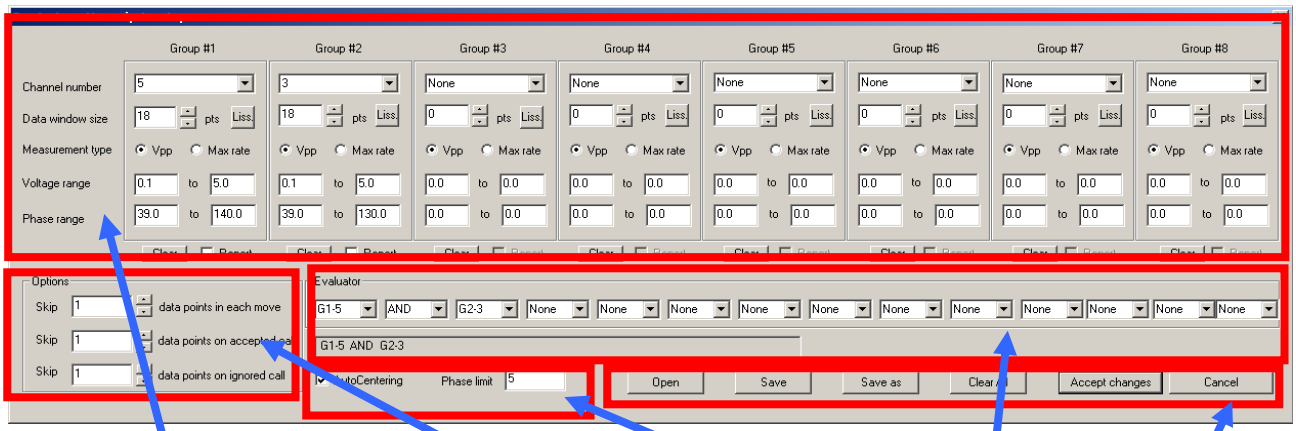


4. DESCRIPTION OF EddyOne AUTOMATED ANALYSIS SOFTWARE

EddyOne Auto analysis is divided in two different types:

1. Semiautomatic Analysis (This means that computer program alone examine the eddy current data, but when it finds some indication in accordance with conditions specified in setup, it will stop and wait for Analyst decision is it, or not, real indication. For detail information about Semiautomatic setup see Figure 10. Please note that semiautomatic is able to accept only one universal complex rule for data screening.

Figure 10. Setup screen for Semiautomatic analysis



Part of the setup screen where conditions for every screening channel are defined. Those conditions are the following per each channel:

5. Size of the screening window
6. Type of measurement which has to be used
7. Voltage range
8. Phase range

Part of the setup screen where speed of screening window is defined, as well characteristic of screening without auto centering feature.

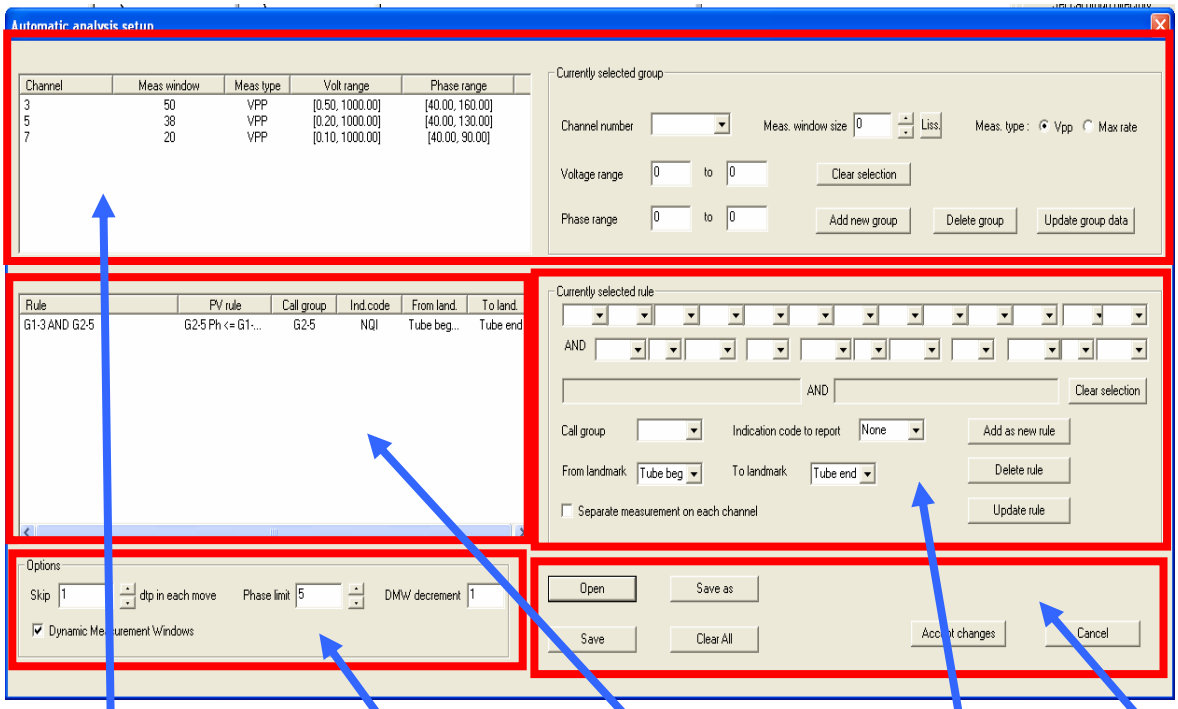
Enabling of auto-centering feature, as well as definition of phase limit used on signals without sharp transition.

Part of the setup screen where possible logic rules between screening channels (called groups) are defined. Logic operators and brackets are available for definition of screening rule.

Part of the setup screen where functions for file handling are defined

2. Full Automatic Analysis usually called only Automatic Analysis. When program find some indication in accordance with conditions specified in setup, program would not stop. It will call that indication and continue to work up to the end of current cal. It means that calling, as reading of next tube is totally automatic. After program finished its work analyst has possibility to review all called data and make eventual changes, if any. Auto-centering option in full Automatic Analysis is always enable)

Figure 11. Setup screen for Full Automatic Analysis



Part of the setup screen where conditions for every screening channel are defined. Those conditions are the following per each channel:

1. Size of the screening window
2. Type of measurement which has to be used
3. Voltage range
4. Phase range

Part of the setup screen where speed of screening window is defined, definition of phase limit used on signals without sharp transition and use of dynamic windows

List of established rules and sub rules.

Part of the setup screen where possible logic rules (unlimited number of rules can be defined) between screening channels are defined. Logic operators and brackets are available for definition of screening rule. Also comparison of phase and voltage values are possible as sub rule(s)

Part of the setup screen where functions for file handling are defined.

Basic characteristics of Semi and Full automatic analysis are given in Table 1.

Table 1. Basic characteristics of Semi and Full automatic analysis

Semi Automatic Analysis	Full Automatic Analysis
Interactive work (on line) with data analysis	Program is doing analysis without interference of data analyst. All changes have to be performed off line after automatic analysis is finished.
Auto-centering feature is an option	Auto-centering feature is always enabled
Up to 8 channels for data screening	Unlimited number of screening channels.
One general rule between screening channels	Unlimited number of rules between screening channels.
No sub-rules regarding comparison of phase and voltage values	Unlimited number of sub-rules between screening channels. Sub-rules are connected to main rules with AND logic operator
Program is screening the whole length of every tube using all defined screening channels.	Program is screening locations of interest selectively. Various parts of tube can be screened with different screening channels and applying different rules between those channels.
Indication codes are defined by data analyst on every call.	Indication codes are automatic and depend on the setup.

5. FIELD RESULTS OBTAIN WITH EddyOne AUTOMATED ANALYSIS SOFTWARE

To evaluate potential of EddyOne Automated analysis INETEC performed Automated analysis on data from three nuclear power plants (8 steam generators, 38521 tubes) with excellent results. On those tubes 237 indications of various types (cracks, dents, bulges, permeability variations, etc.) were approved by data resolution. 98.7% of indications which were found by manual analysis were also found with automated analysis. Additionally 34 indications (mainly of small amplitude and in the noisy environment) were found only by automated analysis. Number of overcalls of Automated analysis was 175 or 0.0045 per inspected tube. For comparison, number of overcalls during manual analysis (primary and secondary) was 162. Summary of these results is given in Table 2.

Table 2. Summary of EddyOne Full Automatic analysis results

Feature	Obtained results
Scope of testing	38521 tubes on 8 steam generators
Number of indications approved by data resolution after manual analysis (primary and secondary) and Automated analysis	237
Efficiency of Automated analysis	98.7 % (ONLY 4 indications were missed because their characteristics were not taken into account during setup process of automated analysis)
Number of indications found only by Automated analysis	34 (mainly small in noisy environment)
Number of overcalls for Automated Analysis	175 or 0.0045 per inspected tube

It is very interesting to compare results obtained with EddyOne software, with results obtained by 3 other Automated analysis software which were tested in Electric Power Research Institute EPRI (see

Table 3). It has to be noted that their results are obtained only on Westinghouse PWR steam generators with several types of indication (data set is chosen on such way that most tubes have some kind of indication(s)) and INETEC results are obtained analyzing all tubes from several regular outages collected on one PWR unit and two WWER units.

Table 3. EPRI results of Automated analysis (see Ref. 1)

Westinghouse Data Set (1355 Common Tubes)

Degradation	System A		System C		System D	
Mechanism Category	Fraction Detected	POD @90% CL	Fraction Detected	POD @90% CL	Fraction Detected	POD @90% CL
ODSCC_TSP	0.90	0.86	0.88	0.84	0.98	0.96
Wear_AVB	0.92	0.90	0.94	0.92	0.94	0.92
Thinning_TSP	0.94	0.88	0.90	0.84	0.92	0.87
ODSCC_FS	0.75	0.59	0.65	0.48	0.95	0.82
PWSCC_TSH	0.90	0.74	1.00	0.89	0.95	0.81
PWSCC_TSP	0.65	0.58	0.90	0.85	0.82	0.75
Wear_TSP	0.94	0.88	0.94	0.88	0.98	0.93
MBM	0.82	0.74	0.88	0.81	0.95	0.89
Composite *	0.88	0.87	0.92	0.90	0.94	0.93
Overcalls	1427 (1.05/tube)		3284 (2.42/tube)		941 (0.69/tube)	

What is surprising on EPRI results is a great number of overcalls. This can be the result of the following:

- inconsistent rules for manual analysis with which referent data base was established;
- improper setup for particular site/steam generator because history data was not taken into account adequately;
- use of too general setups because vendors want to catch everything, even types of indication which are not present in steam generator tubes currently analyzing.

6. DEVELOPMENT DIRECTIONS

The next step in Automated analysis development will be introducing elements of artificial intelligence as:

1. Neural network approach which already demonstrate its abilities on landmark auto-location algorithm. The Beta version is now under testing and release version can be expected in the middle of 2004.
2. Fuzzy logic algorithm which has some promising characteristics.

Intensive field testing will be performed after development of mentioned algorithms.

7. CONCLUSIONS

At the end we can make the following conclusions:

1. EddyOne Automated analysis is an excellent tool for performance of data analysis of steam generator tubes. It can replace data analyst 100% in all situations where all characteristics of data degradation are known. In cases when data analysis is performed on steam generator with unknown degradation characteristics, it has to be used first time in combination with manual analysis. After collecting enough knowledge it can again fully substitute manual analysis.
2. The quality of Automated analysis is a function of quality of its setup, which means indirectly on the quality of the person who run Automated analysis. Under term “quality of the person”, at least the following features have to be taken into account: natural intelligence, theoretical knowledge of eddy current method, manual eddy current analysis skills, years of on site experience and diversity of experience. If one team has not adequate high quality persons to use Automated analysis, it has to be performed in combination with manual analysis. For example primary analysis has to be manual and secondary automated.
3. Development of advanced algorithms based on artificial intelligence will improve automated analysis in the sense of self learning and will completely substitute manual analysis in the near future.

REFERENCES:

1. *Assessment of Automated Data Analysis for Steam Generator Tubing: Eddy Current Bobbin Coil Probes,* EPRI, Palo Alto, CA: 2002. 1003140.