

Advanced Tools based on Simulation for Analysis of Ultrasonic Data

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Abstract

The analysis of ultrasonic data occurs at the final step of nondestructive testing process, and is a critical element for its performance. Phased array technologies add an additional level of complexity, by their ability to combine several modes and several exploration areas. The use of simulation in order to facilitate the interpretation of data acquisition is a relatively untapped area, and opens the way for advanced characterization and automatic inversion.

The first part of this paper presents the module "CIVA Analysis" for ultrasonic NDT data. It includes imaging and reconstruction tools to identify the indications of an inspection. As an example, the segmentation will be described. This feature allows an automatic identification and characterization of indications in a large area of interest.

The second part of this communication will present the "Simulation on Acquisition" feature: from his first diagnosis, the analyst is able to quickly launch a simulation process to understand and interpret certain complex phenomena.

Keywords: CIVA, Analysis, Simulation, Acquisition, Characterization, Segmentation

1. Introduction: A software platform for UT data analysis and simulation

CIVA is a well-known versatile software for the modelling of NDT process that includes different simulation modules for various inspection methods: Ultrasound testing (UT), Guided-wave Testing (GWT), Eddy-Current Testing (ET), Radiographic Testing (RT) and Computed Tomography (CT). Along with its latest version CIVA 2015, this platform also includes now an analysis module for UT acquisition data. The main objectives of this analysis software are to display acquisition data in an easy and understandable way, to extract advanced information in an efficient manner, to put this data into a dynamic report and to avoid repeatable and time consuming operations. In addition to these essential tools for the analysis work, this module benefits from the long experience capitalized in CIVA in modelling innovative UT inspection methods in order to provide the users with advanced and easy to use tools. One example is the segmentation algorithm (now enhanced and automated) that has been used for years and has been qualified for the analysis of inspection data on French nuclear vessels. Innovative reconstruction methods associated to Phased-Array technologies such as the "Total focusing Method" is also available to process UT data, often acquired with the Full Matrix Capture mode. Signal processing tools are other features available to help for Signal to Noise ratio enhancement. Finally, the connection with the simulation part of CIVA provides to the user the possibility to compare easily real data and simulated trials. This helps to understand some phenomena or to highlight the need for an improvement in detection and characterization methods especially when the current results are ambiguous or lead to imprecise diagnosis. Some simplified simulation tools ("Simulation on Acquisition") are even directly available in the CIVA Analysis module itself.

In this paper, after a description of the general process followed during a data analysis, some features of this new analysis software are described, such as the segmentation principle or the "Simulation on Acquisition" tool. Application examples are described to illustrate their use.

2. The process of UT data of analysis

The analysis of ultrasonic data obtained by automated or at least geo-localized acquisitions is usually performed according to one or several procedures and with the use of dedicated software. The analysis objective is to obtain an examination report that lists the operating conditions and the indications present in the inspected component.

The first step in the analysis process is to validate the acquisition, that is to say, to ensure that it is conform to the expected one. The acquisition parameters, its quality and the probes calibration are checked. Then, the analysis procedure may include some preliminary signal processing such as amplitude thresholding, application of Distance Amplitude Curve correction or reconstruction of the data in the accurate frame. For example, let's consider cracks analysis using angular scanning with a linear probe. The challenge is to optimize the visualization of the diffraction echo for an optimal characterization of the defect. In CIVA Analysis, the "limitation" tool allows to select data acquired at different angles. Figure 1 presents an analysis page where the top view (left) and section view (right) for each studied angle are displayed. This provides an overview of the acquired data.

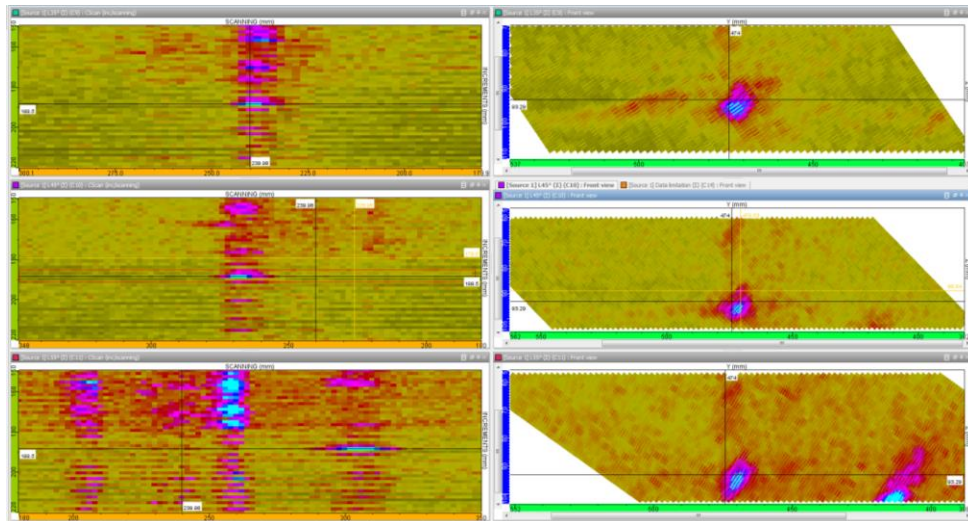


Figure 1: Overview of the data at different angles (35°, 45° and 55° from top to bottom). Images at left are top views and images at right are section views.

Synchronized cursors allow to optimize the limitation of the data (Figure 2) so the user may select the “best” angle to use for side view display. This allows to improve analysis.

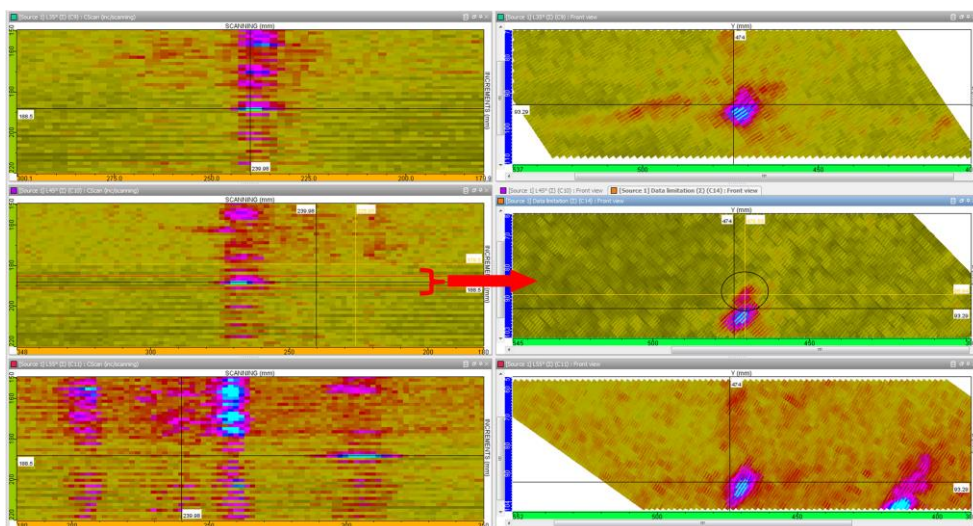


Figure 2: Optimization of the limitation to enhance the diffraction echo detection for the “best” inspection angle

This first step may take time but it needs to be realized only once. Indeed, all the actions described above (limitation, display of specific views,...) can be recorded thanks to the "template" tool and be reapplied to files corresponding to similar controls. Thus, the "template" automates this preliminary step, allowing the user to save time and to focus on the analysis itself.

Once it is done, the procedure imposes detection and characterization thresholds, most of the time defined by standards or codes. The goal is to eliminate false calls or small defects which do not fall within the search criteria. Clustering and segmentation algorithms help quickly determining the echoes of interest which are then studied more finely. The signals evolution according to the probe position, the shape and the position of the echoes, distance measurement and so on are analyzed and noted in an indication table that is resumed in the final examination report. Figure 3 shows the results of application of the segmentation tool to the previously studied angular scanning of a crack. The algorithm will be described more precisely in section 3.

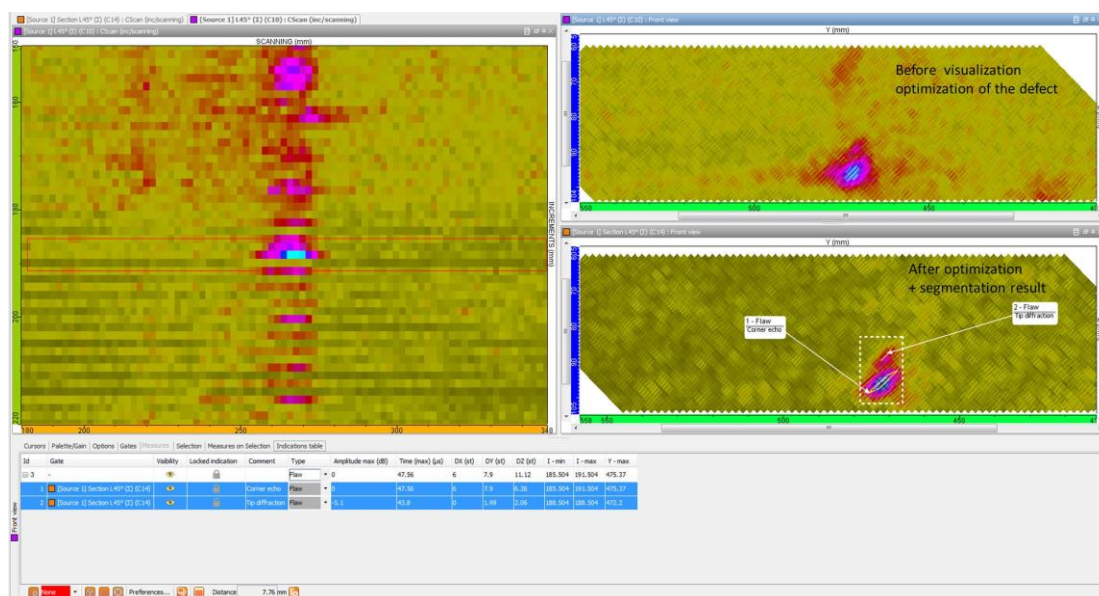


Figure 3: Segmentation result for the defect

Some inspection cases need particular process for both acquisition and analysis. Systems including analysis software were developed and dedicated to these particular cases such as pipe inspection with "zonal discrimination" method. Several suppliers propose solutions. However, these solutions have to be adapted to each case and vigilance is required in order to make sure that influent parameters are under control. In the French nuclear industry, qualification is based on the RSEM code. CIVA simulation software and its associated analysis tools are dedicated for the analysis of inspection data.

3. Segmentation: A powerful algorithm for indications grouping

The goal of the segmentation algorithm is to group signals that come from the same defect or part of a defect. This grouping is based on an algorithm that ensures a more efficient association than a geometrical one (only based on geometrical proximity). This algorithm assumes that locally, the wave front is planar. Thus, the grouping is based on a physical behavior of the ultrasound wave and reduces drastically grouping of false calls such as noise.

The parameters used to set segmentation can also be determined by a physical approach that increases the confidence level of grouping (based on the frequency, the bandwidth and other essential parameters of the transducer). Segmentation is a process that uses experimental or simulated data to compute segments that represent the various echoes. Segmentation can be 2D (applied to a single scan line) or 3D (applied to several consecutive scan lines).

Once the grouping is done, the groups and all relevant information (various possibilities depending on the procedure) can be managed to create the data for the examination report in the way they are required by most codes and norms. Multiple indications can also be grouped as one indication (tip diffraction echoes from a crack for example). One example of segmentation analysis performed in the CIVA UT analysis software is presented below.

4. Analysis of a UT acquisition on a given component

Hereafter, an acquisition performed with M2M systems will be used to illustrate the Smart Segmentation tool of CIVA Analysis and other functionalities. This acquisition corresponds to the inspection in immersion of a composite plate with a 5 MHz phased-array probe of 64 elements. An electronic scanning of 16 elements with null delay law and 1 element step is associated with a Cscan displacement of the probe.

The first thing to do before using the analysis tools of CIVA Analysis when dealing with such acquisition mixing electronic scanning and mechanical scanning is to concatenate the data. This allows to visualize the data coming from these two collinear axes of scanning (electronic and mechanical) on the same view. This also eases the reading and understanding of the recorded signals. Figure 4 shows the differences in the Cscan view after application of the concatenation tool.

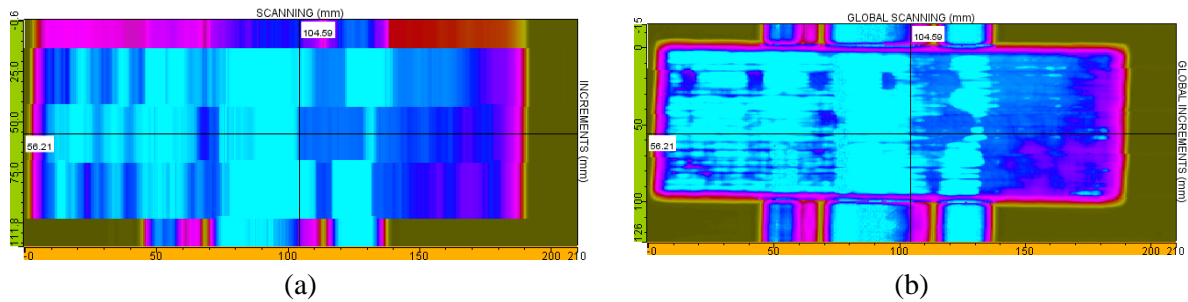


Figure 4. Modification of the Cscan view after application of the concatenation tool – (a) before concatenation, (b) after concatenation.

Figure 5(a) shows the Bscan view for a specific increment index of the probe. The defects to be identified are located between the surface and backwall echo. The use of temporal gates will allow to isolate the flaw's responses in CIVA Analysis. As it can be seen, the surface echo is not perfectly horizontal. This is due to a slight mismatch in parallelism between the probe and the specimen. Therefore, a simple gate between the 2 geometry echoes is not sufficient since it will not be defined with the same time bounds for all probe positions. In CIVA Analysis, it is possible to define several gates and synchronize them in order to display only the different views in the desired temporal gate. For this particular case, two additional temporal windows will be used. The first one is associated with the entry echo (pink gate on Figure 5(b)) and the last one (blue gate) and includes the signals between the geometry echoes. This one is synchronized with the maximum echo of the entry echo in order to overcome with the change in time of flight of the entry echo.

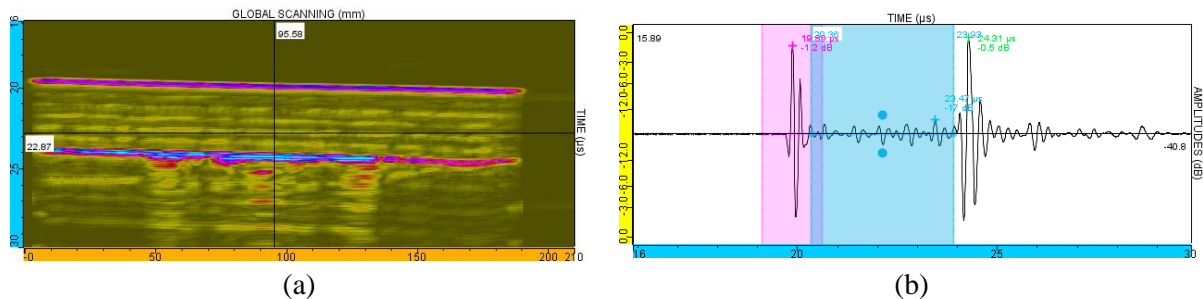


Figure 5. Use of temporal gates in CIVA Analysis.

The result of the application of the temporal gates is presented on Figure 6 where several indications, certainly flaw echoes can be observed.

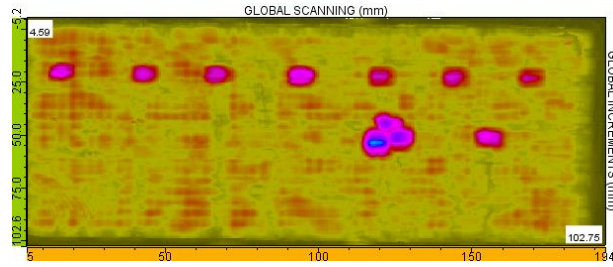


Figure 6. Cscan after application of temporal gates.

Then, the “Smart Segmentation” is a tool to assist in analysis. It allows the user to detect, in a Region Of Interest (ROI), indications that correspond to a predefined set of criteria.

First, the user defines a ROI containing the data to be segmented with the “selection” tool. Then, clicking on the segmentation button makes Segmentation (parameters) and Segmentation results toolboxes (Figure 7) appear. The user can adjust the “threshold” on the amplitude, the spatial and temporal resolution defining the grouping parameters, and the “tempo” parameter. The threshold corresponds to an amplitude level above which the signal will be taken into account during the analysis. The spatial resolution is the number of successive shots considered to group information. The temporal resolution is the time window in which the processing will join two points of consecutive shots by a segment. Finally, the “tempo” parameter is the time window in each A-scan in which we keep only one echo. This must be in correspondence with the width of the signal (and the bandwidth). Note that all these parameters are set to pertinent values by default and should give an interesting result by a simple click with no adjustment except the threshold that has to be in accordance with the procedure and the noise level.

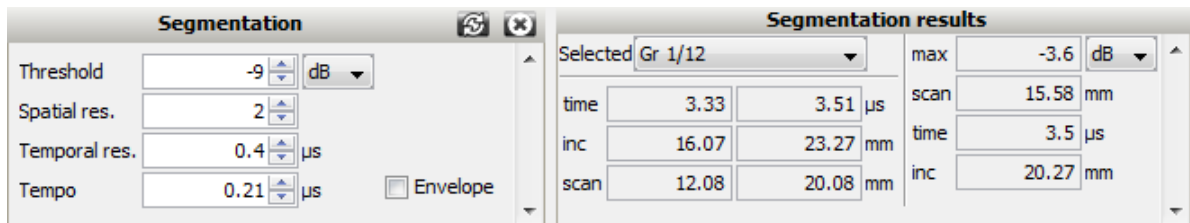


Figure 7. Segmentation toolboxes.

The results of the segmentation are displayed on the views in the layout (Figure 8). Twelve indications were found, corresponding to 12 possible defects.

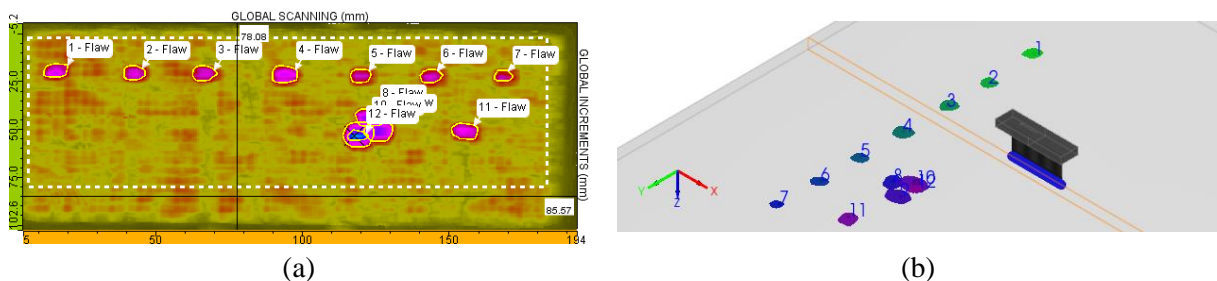


Figure 8. Display of the groups after segmentation (a) on the Cscan, (b) on the 3D view.

Relevant information (amplitude, position, size...) is included in an indication table in one click: images, distances, type of indication or other comments can be added. Multiple indications can be grouped as one indication. Columns of this indication table can be selected, sorted among a long list of available data. This indication table can be exported in CSV format or an HTML report can be generated in one click.

Id	Gate	Visibility	Locked indication	Comment	Type	Amplitude max (dB)	Time (max) (μs)	DX (st)	DY (st)	DZ (st)
1	[Source 1] Gate 3 (Σ) (C10)	👁	🔒		Flaw	-3.6	3.5	7.2	8	0.24
2	[Source 1] Gate 3 (Σ) (C10)	👁	🔒		Flaw	-5.1	3.99	7.2	7	0.05
3	[Source 1] Gate 3 (Σ) (C10)	👁	🔒		Flaw	-5.3	3.55	7.8	8.5	0.21
4	[Source 1] Gate 3 (Σ) (C10)	👁	🔒		Flaw	-3.7	2.98	9	8.5	0.23
5	[Source 1] Gate 3 (Σ) (C10)	👁	🔒		Flaw	-5.8	2.67	7.2	7	0.21
6	[Source 1] Gate 3 (Σ) (C10)	👁	🔒		Flaw	-5.3	2.47	7.2	7.5	0.21
7	[Source 1] Gate 3 (Σ) (C10)	👁	🔒		Flaw	-6.3	1.86	5.4	6	0.05
8	[Source 1] Gate 3 (Σ) (C10)	👁	🔒		Flaw	-2.3	2.58	8.8	9.5	0.12
9	[Source 1] Gate 3 (Σ) (C10)	👁	🔒		Flaw	-2.1	3.97	12	9.5	0.23
10	[Source 1] Gate 3 (Σ) (C10)	👁	🔒		Flaw	-0.6	1.53	13.2	10.5	0.09
11	[Source 1] Gate 3 (Σ) (C10)	👁	🔒		Flaw	-4.3	1.6	8.4	9	0.03
12	[Source 1] Gate 3 (Σ) (C10)	👁	🔒		Flaw	-5.3	2.97	5.4	7	0.07

Figure 9. Indication table.

In parallel, to help with the diagnosis, multiple functionalities are available: a wide range of signal processing methods, some are classical (filters, etc.), others are more sophisticated (wavelet transforms, deconvolution methods, Split Spectrum).

5. Simulation on Acquisition: To help the diagnosis

The stand-alone version of CIVA UT Analysis module also proposes to perform a simulation in a ROI of the acquisition in order to enhance diagnosis.

To illustrate the usefulness of the “simulation-acquisition” tool, let’s consider the following acquisition corresponding to the inspection of a mock-up representative of a NDT configuration. The component is made of homogeneous stainless steel; the surface is disturbed by a butt weld while the backwall is made up of two slopes of $\pm 10^\circ$ linked by a bead weld. The control is performed with a 2 MHz phased-array probe of 48 elements. A focused angular scanning is applied to cover the region of the welding (Figure 10).

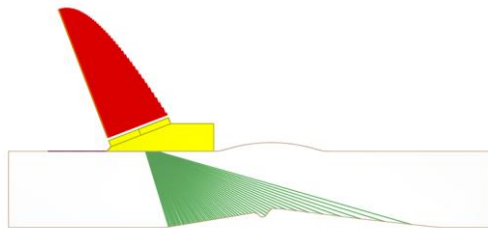


Figure 10. Configuration of the inspection.

Figure 11 shows the S-scan obtained after acquisition. Three echoes can be distinguished. There is no uncertainty on the origin of echoes n°1 and n°2 which correspond to geometry echoes from the backwall (respectively direct echo and conversion mode echo). On the other hand, the origin of echo n°3 is less clear. This echo may be a geometry echo from the bead weld or the echo from a flaw, probably from a tilted planar defect.

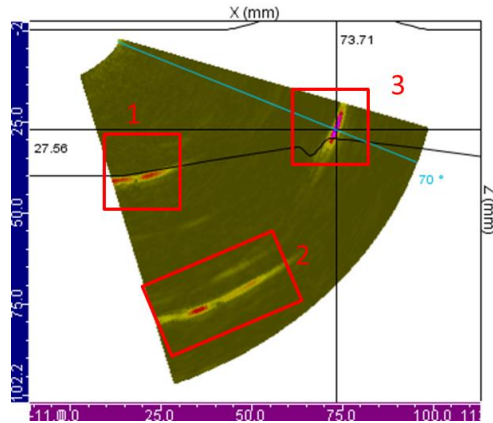


Figure 11. Result from the acquisition.

Because such uncertainty may not be acceptable for safety reason, CIVA Analysis users may remove doubt with the “simulation on acquisition” tool. To access this option, a ROI must be selected then the user activates the “Simulation on acquisition” tool.

A new page opens and offers to choose the options for simulation (Figure 12).

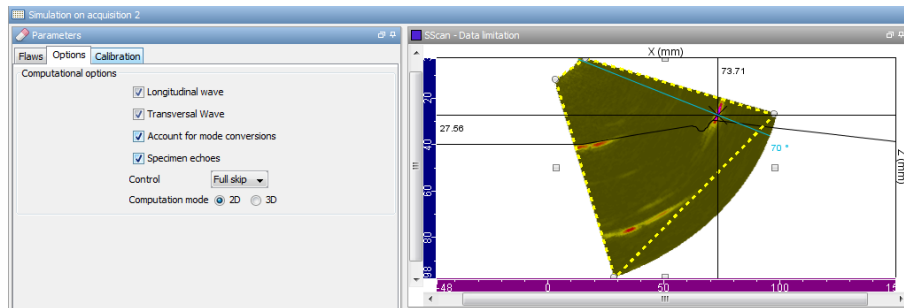


Figure 12. Simulation on acquisition panel.

The simulation is performed in the ROI where specimen echoes and flaws (planar defects and side drilled holes only) responses may be calculated. As a first step, let's consider that echo n°3 is a geometrical echo. Thus, no defects will be simulated. The calculation result is shown on Figure 13 (image on the right) where it can be seen that the echoes n°1 and n°2 are well simulated whereas echo n°3 is absent.

Note that, the user has the choice between automatic and manual calibration of the amplitude of the simulated data. With automatic calibration, the maximum of amplitude in the simulated area is calibrated with the maximum one of the acquisition in the same zone. However, it is possible to adjust the dynamic afterwards.

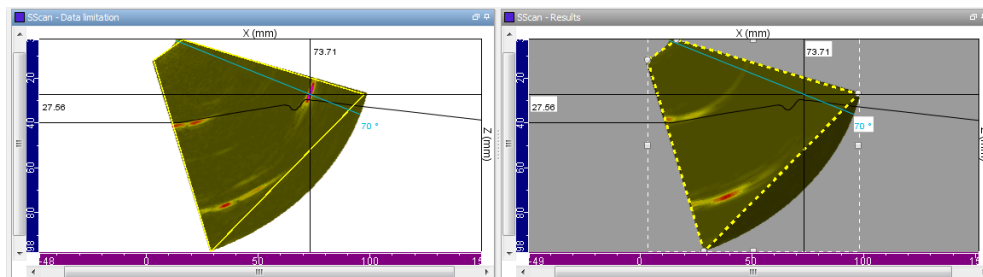


Figure 13. Comparison of the experimental S-scan (on the left) and the simulated one (on the right) without flaw.

The comparison of Figure 13 allows to confirm that echo n°3 is not a geometrical echo from the bead weld. The “simulation on acquisition” is then used with flaw response to check that the echo of interest comes from a planar flaw. This time, the ROI where will be applied the simulation is located around the zone of echo n°1 (Figure 14)

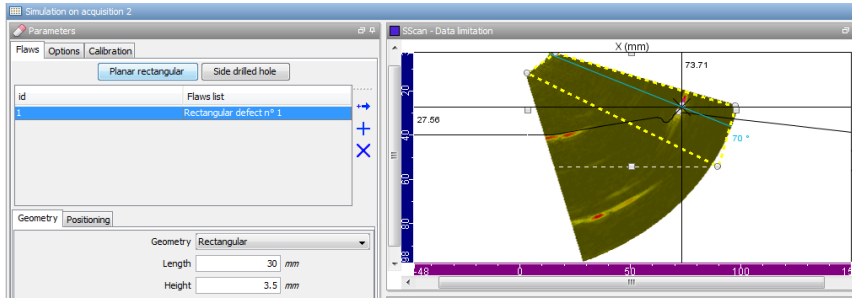


Figure 14. Flaw panel of the simulation on acquisition tool.

In the flaw tab of the simulation on acquisition panel, one rectangular defect is added which position and characteristics (height, tilt...) were based on the position of the echo (Figure 15). The defect location in the specimen can be adjusted with the mouse directly in the True image (e.g. True Bscan or True Sscan) where is shown the ROI. It is also possible in the 3D view where the S-scan can be dropped. This allows better fitting of the flaw position and orientation according to the one of the echo.

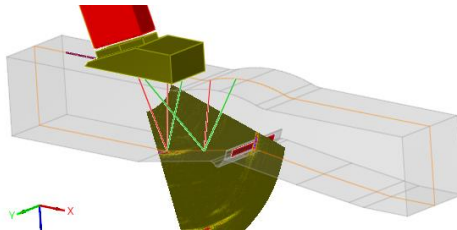


Figure 15. 3D view of the specimen and flaw with the S-scan.

Figure 16 show the result of the simulation in the ROI on the S-scan.

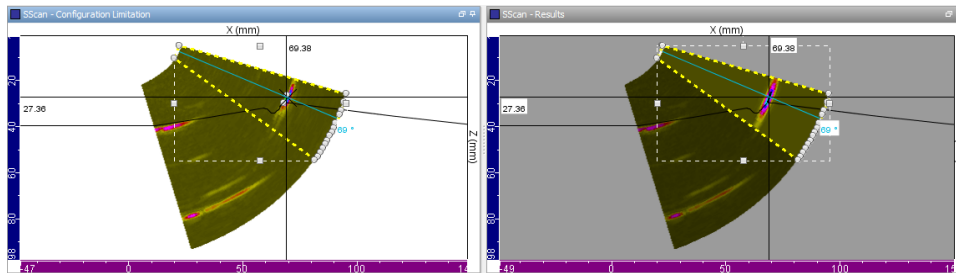


Figure 16. Comparison of the experimental S-scan (on the left) and the simulated one (on the right) with flaw.

An echo close to the experimental one has been obtained by simulation. This confirms that the echo n°3 belongs to a notch. The Ascans and echodynamic curves of the simulated data can be superimposed to experimental ones in order to compare the result (Figure 17). There is a good agreement between experiment and simulation. Simulations may be computed in 2D or 3D. In a first approach, 2D computation can be used. It presents the advantage of fast computation (in this example 2D simulation takes 3 seconds). Then, 3D computation which requires more computation time (1 minute 20s) may be considered especially when dealing with 3D cases and phenomena. The result will be thus more accurate for complex configurations.

Note that only planar defects and side drilled holes may be simulated in the CIVA Analysis module. Simulations with many more complex flaws may be performed in the full simulation software "CIVA 2015".

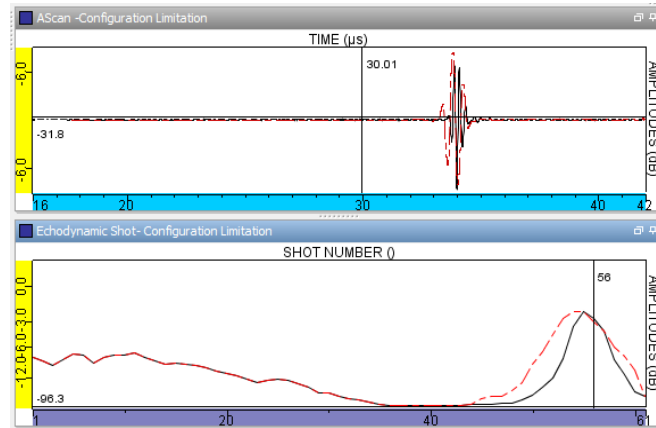


Figure 17. Comparison of experimental and simulated Ascans and echodynamic curves. In red, the result of simulation, in black the experimental data.

This example and the associated results show that the “simulation on acquisition” tool may help to better diagnosis of experimental acquisitions.

6. Conclusion

This article has introduced some of the tools available in the new UT analysis software, available with the CIVA platform. Among them, the principle and application of the segmentation algorithm have been detailed, this one being now available as an automatic tool. The interest of the “Simulation on Acquisition” feature has also been illustrated on an example where it can help to confirm or disprove a given diagnosis, especially when the acquisition data involves complex signals. Thus, CIVA Analysis module is a tool providing manual data inversion assisted by simulation. Ongoing developments at CEA aim to develop increasingly automated tools in order to improve and ease the detection and characterization of the flaws. Today, this software can be used to process acquisition data from various formats (M2M systems, Gekko, Olympus Data). As an option, full simulation modules can be used along with the analysis part to help in expertise or design works.