International Workshop
SMART MATERIALS, STRUCTURES & NDT in AEROSPACE
Conference
NDT in Canada 2011
2 - 4 November 2011, Montreal, Quebec, Canada

RECENT EVOLUTIONS OF THE CIVA SIMULATION PLATFORM AND APPLICATIONS

Fabrice FOUCHER, Roman FERNANDEZ, Philippe DUBOIS
EXTENDE,
86 rue de Paris, Bâtiment Erable, 91400 ORSAY, France
contact@extende.com, www.extende.com

ABSTRACT

The CIVA platform dedicated to the modeling of NDT techniques is now extensively used in different industrial sectors. This simulation tool is developed by CEA LIST and benefits also from the contribution of numerous partners from industry and universities. Used during the design stage of a new component or for the performance demonstration of an in-service inspection method, the simulation tool supports productivity improvement, for instance by reducing the number of necessary mock-ups and experimental trials. It also helps to introduce innovative processes such as multi-element methods. Simulation serves an additional useful purpose by producing realistic inspection results that will confirm or disprove a diagnosis. Another aspect of the simulation is to try to reproduce realistic inspection results within a range of allowable parameters such as surface finish and geometry in order to better understand the relationship between inspection parameters and variations in the part being inspected. This article introduces some of the latest developments now available in CIVA as well as some applications in UT, ET and RT.

THE CIVA SOFTWARE PACKAGE

The simulation plays an increasing role in NDT, allowing to help the design of inspection methods, their qualifications or the analysis of inspection results.

The CIVA software package can simulate today 3 major techniques: Ultrasonic Testing (UT), Eddy Current Testing (ET) & Radiographic Testing (RT). These three modules are available in the same environment, bringing to the users a unique NDT oriented Graphical User Interface and some dedicated tools, which make its use quite easy.

The mathematical formulations used in the different modules rely on semi-analytical models. This approach allows solving a large range of applications while offering very competitive calculation time if you compare with purely numerical methods (FEA, etc.).

To summarize the different models, one can be indicated that the UT module relies on a rays theory geometrical approach, the so-called “pencil method”, to compute beam propagation. The

interaction with defects is calculated using either "Kirchhoff" approximation or the geometrical theory of diffraction (« GTD »).
The Eddy current module involves a Volume Integral Method which only requires a numerical sampling of the flaw, the electromagnetic field induced in the work piece being calculated analytically.
Finally, the X-ray and Gamma-ray tool uses a « rays » approach associated to the Beer-Lambert straight line attenuation model to compute direct radiation. The scattering radiation is solved thanks to a probabilistic approach (Monte-Carlo method) allowing to reproduce photons/matter interaction phenomena.
For interested readers wishing to have more information on the models, the following reference papers are available, [1] for the Ultrasonic tool, [2] for the Eddy Current module and [3] for the radiographic part.
One of the main advantages of the semi-analytical approach is to make possible the solving of parametric studies with time compatible with industrial use (sensitivity study, tracking of the best design or of the worst case scenario, etc.). By giving quantitative and numerous results, in a relatively short time and integrated in an intuitive environment, the simulation can constitute a real benefit to optimize performances and cost efficiency in a NDT process.
Some validation works of the different codes are performed, including the participation to international benchmarks [4].

LATEST MODELLING CAPABILITIES

The CIVA platform regularly proposes new releases in which improvements are included. In CIVA 10.0, new capabilities of simulation are offered in the three techniques.
For instance, it is now possible to simulate in CIVA UT, the inspection of work piece having complex geometries defined in 3D CAD. More realistic defect profiles can also (now) be accounted for such as branched defects. The number of modes you can take into account has also been extended, with multiple skips in the UT paths or with the accounting for the contribution of some creeping waves' phenomenon in addition to bulk waves signals. Another new model has been implemented to simulate coarse grain structures, as you can find in cast stainless steels, with which user can reproduce the effect of such metallurgical structure on the beam propagation.
In the Eddy Current simulation tool, it can be noticed that new sensors can be defined and particularly innovative probes such as Eddy Current arrays or GMR magnetic sensors (Giant Magneto Resistance). Another new capability available in this module is to be able to simulate multiple flaws such as a longitudinal notch combined with a transverse notch.
In the RT module, the version 10 developments have focused on the improvement of the ergonomics of the software and its computation performances. For instance, the scattered radiation based on a Monte-Carlo method, has been parallelized, which makes this type of computation much faster. It is now possible to include realistic scattering computations in 1 or 2 hours. Moreover, once this part of the calculation has been done once, it can be reused for additional simulations, particularly if you want to study the effect of the exposure time on the radiographic image. Such parametric studies are then performed in a few minutes.
Finally, another major new capability is to compute POD curves from simulation results.
The user describes the uncertain input parameter and their variation ranges (for instance, the orientation of the flaw, some parameters of the transducers, metallurgical noise, etc.), then CIVA runs series of computations picking some different values for these uncertain parameters among their statistical distributions. As a result, this manages to reproduce the variability of the defect

response signal due to these uncertainties. Compared to the detection threshold of the inspection procedure, the POD curve can then be plotted. These simulated data can then replace a part of the experimental tests done on mock-ups while enlarging and maybe better controlling the variation of the influential parameters.

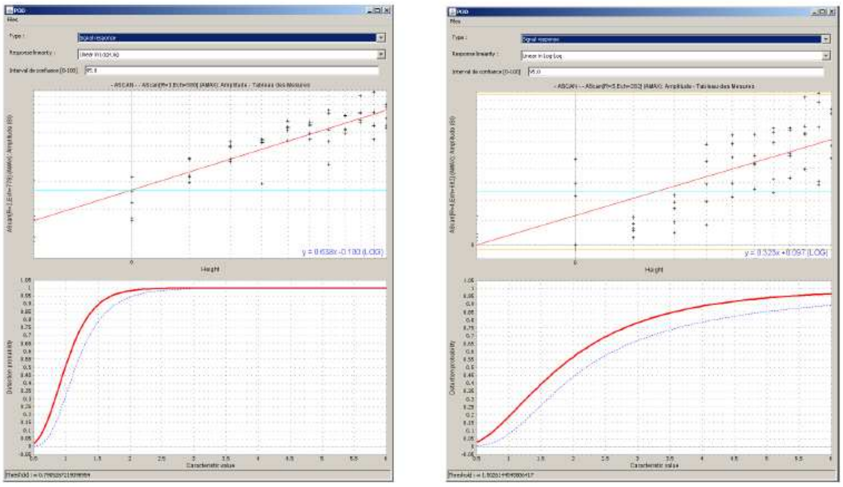

Figure 1: Examples of POD curves obtained from CIVA simulations

On the figure 1, two POD curves are plotted corresponding to the simulation of a stainless steel specimen with a T45 probe. Two different levels of metallurgical noise are described in these two cases. More information on POD curves modeling and on this application case are give in the reference paper [5].

CIVA: APPLICATION TO PERFORMANCE DEMONSTRATION

Modeling is particularly interesting in the framework of the qualification of inspection methods. Building a justification report implies to study the sensitivity of the method to influential parameters in order to demonstrate its reliability and to better understand its limits.
By definition, it is then necessary to vary parameters (flaw position or orientation, transducers properties) around their nominal values.
The case of a thermal sleeve in pressure vessels steam generators is shown below. The testing is made with a contact angle transducer using shear waves at 45°. Figure 2 presents the nominal configuration and a first result for one given position of the flaw.

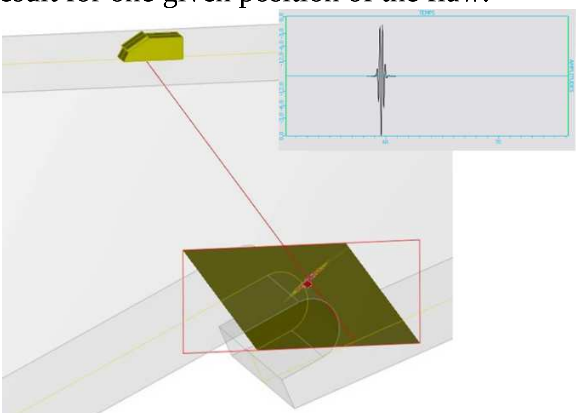

Figure 2: Thermal Sleeve inspection configuration

The qualification of this inspection requires studying the sensitivity of the defect response versus the angular position of this flaw around the sleeve (see figure 3). Even if it is possible to build a mock-up or several mock-ups for each defect positions and do some measurements, this approach is quite costly and time consuming. A more efficient method proposed here, was to realize a mock-up for two positions only, and then to complete the experimental trials with a simulation parametric study. The comparison between measurements on the existing mock-ups and simulation results allows validating the model on a few cases. Then, the whole variation range is studied by simulation, and then the required results are obtained, to be compared with the detection criteria defined for this control.

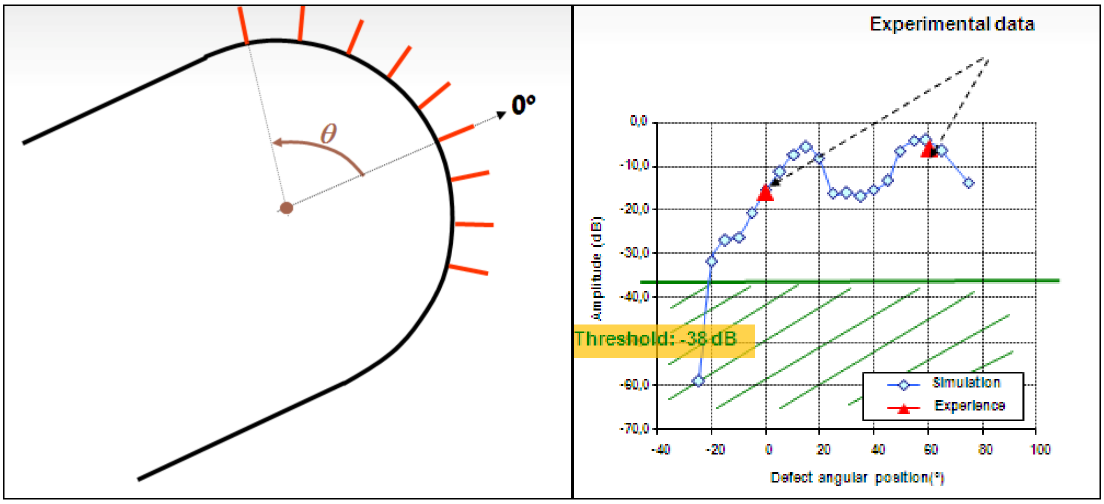

Figure 3: Study of different flaws positions / Simulation data validated by 2 experimental results

CIVA: APPLICATION TO THE INTRODUCTION OF INNOVATIVE TECHNOLOGIES

Another benefit of the simulation is the ability to help the introduction of innovative inspection methods. Pre-design tests can be done at a quite low cost which will give the first answers, allowing minimizing the iteration of the prototyping phase. The realization of the prototypes is then faster and more efficient. Earlier in the process, you can also use the simulation to compare the performance of an innovative sensor to a conventional one, before deciding to change and to invest in the new technology.

The design of an Eddy Current array can be an example of such an innovative sensor. On the figure 4, you can see an eddy current array made with a set of micro-coils, designed by the CEA with the help of CIVA. The probe is here composed of 64 micro-coils positioned on 2 layers of 32 elements, separated by a kapton film and assembled on a flexible support.

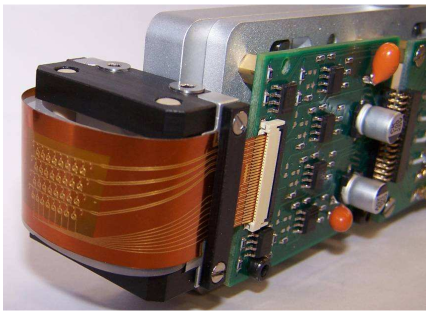

Figure 4: Flexible ET array probe

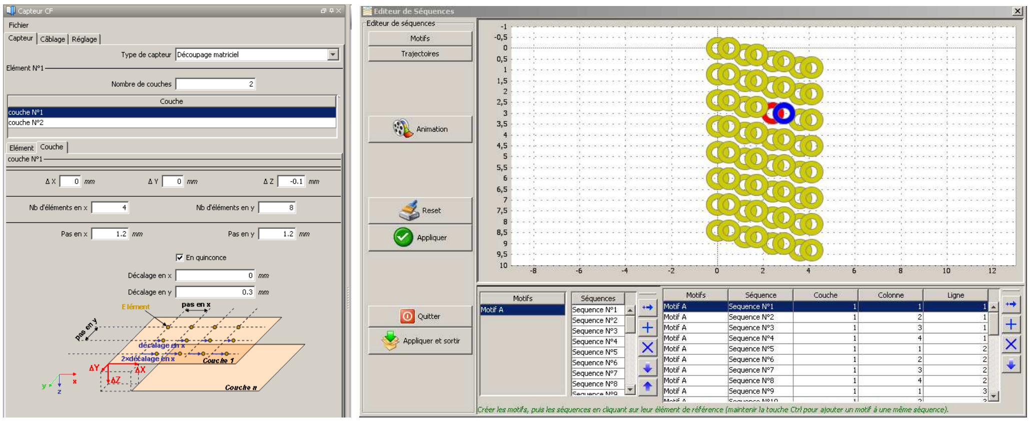

Figure 5: Specific Interface of CIVA ET to define and control array sensors

This multi-elements technology has significant advantages compared to a conventional one made with standard wounded sensors. First of all, it allows detecting small indications with a very good resolution. Then, the benefit of multi-elements is to require less position of acquisitions and then decrease the mechanical scanning, therefore the inspection time. Moreover, the electronic management of the arrays allows to benefit from multiple inspection channels. Finally, the flexibility of this probe assembled on a silicon roll ensures a good contact with the work piece, even with an irregular profile, and decreases the level of parasitic signals due to lift-off variation (see [6] for more information on this probe).

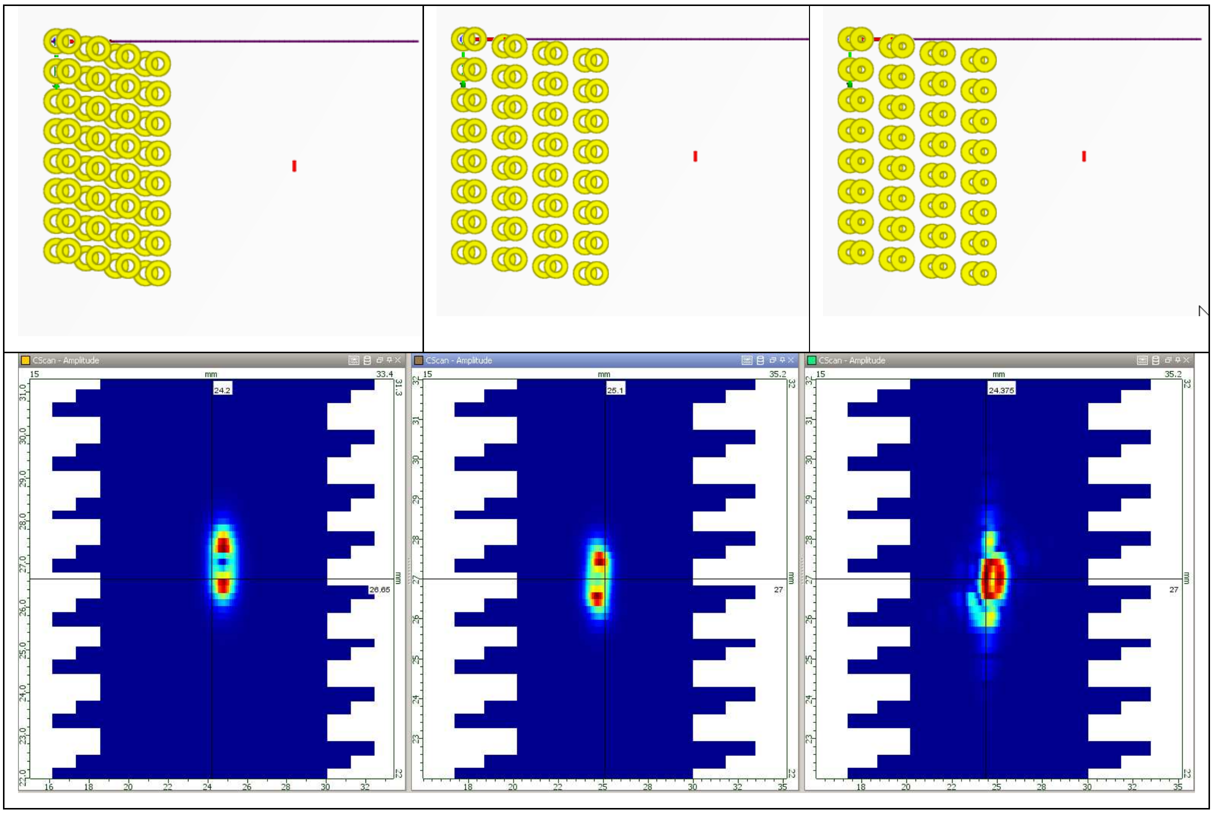

Figure 6: Different designs evaluated by simulation / Cscans of the obtained signal amplitude

For this type of technology, not yet commonly used in the industry, the design process can be quite long, few experiences and few feedbacks being available.
The simulation makes possible to explore the different possibilities at a quite low cost in order to reach a given level of performance (minimum size of flaw to detect, Signal to Noise Ratio, etc.). The size of the elements, the gap between the elements, the operating frequency (ies), the acquisition modes (separate Transmit/Receive, common mode, etc.) are variable parameters that will affect the performance of the probe and that you can define and change very fast in CIVA.
On the figure 6, one can see 3 different set up of matrix arrays of 64 micro-coils with different coils dimensions, different inter-coils distances, and different acquisition modes. These different solutions are tested on the simulation of the defect response of a 0.4mm*0.2mm*0.1mm flaw, located in an inconel slab. A linear mechanical scanning is performed. It can be noticed on the 3 obtained Cscan that the defect signal significantly changes between each cases.

CIVA: APPLICATION TO THE PREPARATION OF AN INSPECTION

To prepare an inspection is not an easy task as multiple influential parameters have to be considered. In this context, it is particularly interesting to have the possibility to predict the performance of the inspection technique versus these parameters. For instance, in an X-ray inspection, before doing the radiographic shots, it is necessary to:

- Select the adapted source
- Define the positioning and the orientation of this source
- Select the exposure time to obtain a readable radiogram
- To use the good class of film

A bad choice in one of these parameters will lead to the realization of additional shots, which is costly, particularly for in service inspections. To optimize the inspection methods and their time, all of these parameters can be preliminary tested by simulations.
If you consider the source for instance, depending on the thickness of the work piece and the density of the material(s), an appropriate X-ray source has to be selected. An over-energetic source will saturate the film whereas an under-energetic source will stop most of the photons in the specimen and the radiogram will not be sufficiently exposed whatever the exposure time is. The application below deals with a stiffener inspection. The 3D CAD model of the stiffener is imported inside CIVA. It includes a crack of 300µm aperture (see figure 7).

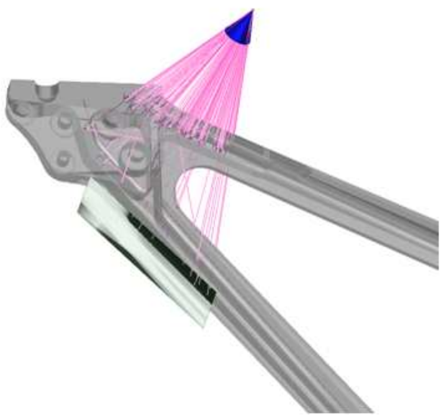

Figure 7: Configuration of a radiographic inspection in the CIVA interface

Simulations are performed for 3 different acceleration voltages. It can be seen that the inspection with a 140 kV source does not allow detecting the crack whereas the indication can be seen with the 200kV source, but does not remain obvious to detect. The optical density values (OD) obtained on this film are not high enough to have a clear signature for this flaw. By contrast, the 300kV source produces an image where the crack can be clearly detected: The OD value at the location of the flaw is about 3.5, and the contrast is large enough to distinguish the flaw. This source is then the good choice for this inspection. These results are given on figures 8 & 9. Select the source to be used thanks to simulation gives the great advantage to noticeably reduce the number of shots to perform on site.

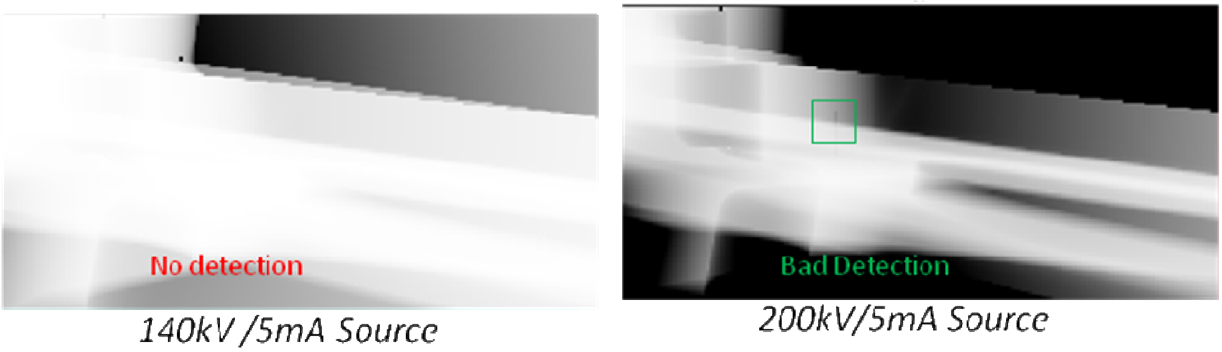

Figure 8: Simulation result with a 140kV source and a 200kV source

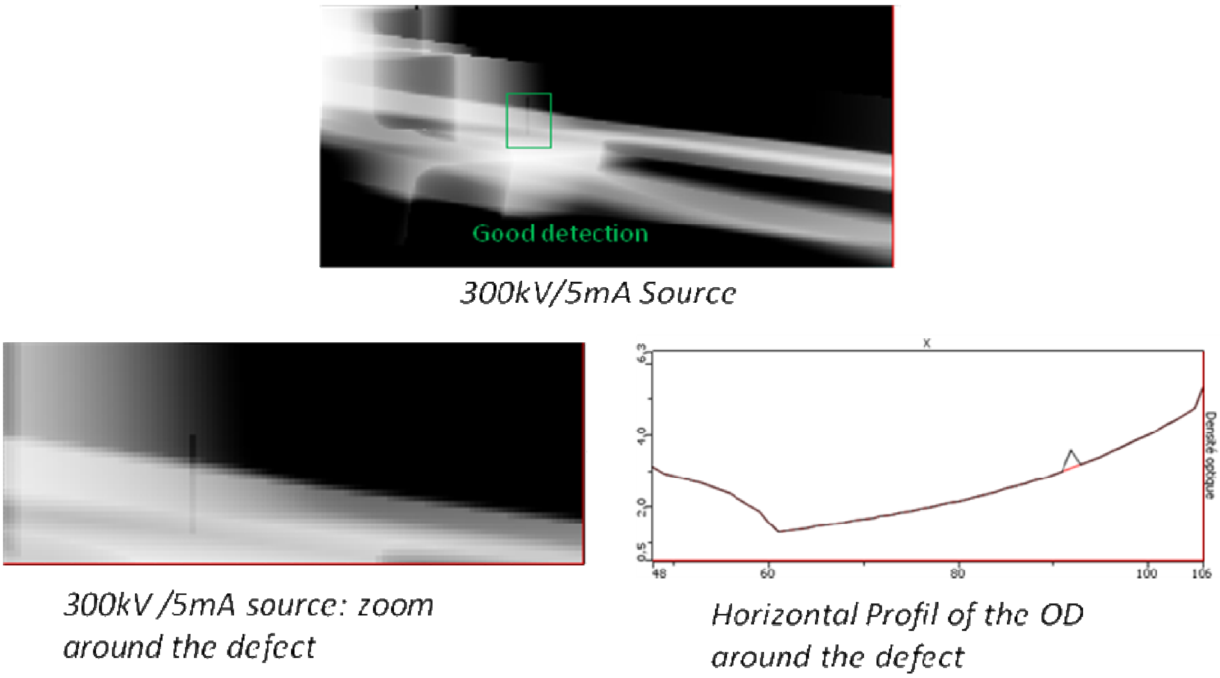

Figure 9: Simulation results with a 300kV source

CONCLUSION

In this paper, some of the latest developments available in the CIVA platform are presented, for the simulation of UT, ET and RT inspections. It can be mentioned particularly the new capability to take into account the uncertain parameters in a control allowing to compute and build POD curves. Several application examples are presented that illustrate the interest of the simulation all along the NDE process, whether it is for the design of a new technology, to set up an inspection or to qualify a given testing method.

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