Automation of simulation supported POD computations with CIVA for power generation industry

Sébastien LONNE*, Jérémie GAINE*, Fabrice FOUCHER*,
Stéphane LABORDE**,
Armin HEGER**, Kurt STEIGLEDER**
*EXTENDE,
15 Avenue Emile Baudot, Le Bergson, 91300 MASSY, France
**ALSTOM (Switzerland) Ltd,
contact@extende.com, www.extende.com

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Abstract

Simulation of NDT is extensively used in different industries worldwide including the power industry. Used at the relevant stage, simulation allows reducing costs by decreasing the number of necessary mock-ups and measurements. For UT inspections of some components used in electric power plants, the testing performance evaluation requires the determination of a Probability of Detection value (PoD). In this case, the PoD value is based on the comparison between the ultrasonic inspection results expressed in ERS unit (Equivalent Reflector Size) and the real size of the flaw, considering the different transducers used for the inspection and accounting for the potential variability of influential parameters (type and orientation of flaws, uncertainties of transducer properties, etc.). As a PoD study relies on a lot of inspection results, this is particularly costly and time consuming, and this is a typical case where simulation helps to dramatically reduce the number of mock-ups and physical tests.
Nowadays, CIVA is considered as the reference tool worldwide for simulating NDT and ALSTOM wished to use CIVA in order to support PoD studies with simulation. However, generating the required data is challenging especially because ERS values are not provided as default outputs from CIVA simulations. Then, conducting a PoD study requires running a lot of cases in order to cover the potential values of influential parameters for the uncertain data. Analyzing individual results and converting them manually in ERS unit would be prohibitive for a reasonable study. Finally, the PoD estimation requires accounting for different transducers which means repeating the same process for the different inspection cases and mixing-up the results in the relevant way. Once again, without automation, the process is really difficult to implement. Then, ALSTOM and EXTENDE worked together to develop a methodology associated with CIVA in order to make this kind of UT simulations more efficient. The tools developed by EXTENDE and allowing automation of the simulation process are presented in this paper.

1. Introduction

As in other sectors, the UT inspection of the critical components existing in electrical power plants requires a qualification stage allowing assessing the reliability of the testing procedure. One way to achieve this reliability study is to compute the Probability of Detection of a given type of flaws for a given inspection. As a PoD study relies on a lot of inspection results, this is particularly costly and time consuming, and this is a typical case where simulation helps to reduce the number of mock-ups and physical tests. ALSTOM wishes to use the simulation tool CIVA for this purpose. However, due to the type of PoD value requested here by ALSTOM Power, the simulation process itself was not easy to manage. That is why ALSTOM worked with EXTENDE in order to develop a tool allowing to monitor CIVA PoD computations in a cost efficient way. The PoD methodology and the associated tool are described in this paper.

2. CIVA: A simulation platform for NDT

The CIVA software package can simulate the major NDT methods: Ultrasonic Testing (UT) including conventional UT, Phased-array UT, TOFD or Guided Waves Testing (GWT), Eddy Current Testing (ET), Radiographic Testing (RT), and Computed Tomography (CT). All these NDT techniques are available in the same simulation environment. Simulation aims at helping people reducing costs induced by mock-ups and prototypes involved in the development and qualification of an inspection. Of course, some physical tests remains absolutely essential but many unnecessary trials could be avoided if simulation tests are performed preliminary, thus, time and money can be saved. In the framework of a PoD study, generally requiring numerous mock-ups, the simulation is particularly cost and time saving. By the way, by producing results in a comprehensive and user-friendly imaging environment, simulation allow to help dramatically the understanding of physical phenomena and therefore to ease technical discussions between experts, inspectors, customers, contractors and suppliers. Simulation can also serves as an expertise purpose by producing realistic inspection results that can confirm or disprove a real diagnosis.

The mathematical formulations used in the different modules generally rely on semi-analytical models. This approach allows solving a large range of applications while offering very competitive calculation time compared with purely numerical methods (FEA, etc.). The UT module relies on a ray theory geometrical approach to compute beam propagation, the so-called "pencil method". The interaction with defects is calculated using either "Kirchhoff" approximation or the Geometrical Theory of Diffraction "GTD" for crack-like flaws. In CIVA 11, a mixed-up "Kirchhoff and GTD" model has been developed in order to allow a precise prediction of both reflection-like and diffraction-like echoes in a single calculation. For volumetric flaws, other models are used (SOV, Born). For some configurations, in order to address critical phenomena or to account for interactions between several flaws, a coupling between semi-analytical and FEM methods has been developed (CIVA ATHENA2D module). For interested readers wishing to have more information on the models of the ultrasonic tool, the following reference paper is available [1].

3. PoD methodology used for this inspection

For the inspection of several components of power plants, ALSTOM Power uses an experimental PoD approach in order to estimate the reliability of an inspection procedure. The PoD indicates the capacity of a system to detect relevant indications, taking into account the variability of defects, generally in terms of dimensions, orientation and location.

The flaws considered for the considered inspection are rectangular notches of various dimensions and orientations. The study of the detectability of the PoD requires accounting for the variability of the uncertain and influential parameters. In this case, the following parameters were considered as the variables. For each of them a range of variation can be defined with an associated statistical law based on the knowledge available for this type of defect. On this particular case, for the purpose of the tool development, the orientation is assumed to be uniform between 0 and 180°, which would not be the case for a real PoD study where a preferential orientation would have been defined for a specific type of flaw.

Table 1. Variable parameters

Variable parameter	Variation range
Flaw length	Uniform distribution: 1 to 3 mm
Flaw height	Uniform distribution: 1 to 10 mm
Tilt	Uniform distribution: 0 to 90°
Skew	Uniform distribution: 0 to 90°
Disorientation	Uniform distribution: 0 to 180°
Radial position	Uniform distribution: 0 to radius
Axial position	Uniform distribution: 0 to 60 mm

Several transducers are involved here, at different angles. For instance, you can see on the figure 2, the image of the ultrasonic field corresponding to L0 and T45 probes, simulated by CIVA. The PoD methodology used in ALSTOM considers the final PoD value as the ratio of the number of detected flaws by the total number of flaws existing in a mock-up and for the whole set of transducers used in this inspection.
For the PoD defined in the project, the detection criterion takes into account the ERS (Equivalent Reflector Size) of the indication corrected by a safety factor "*fs*". The ERS corresponds to the diameter of the FBH at the same depth which would give the same amplitude response:
The detection is agreed when the corrected ERS disc surface is larger than the actual flaw surface, which can be expressed as (1):

$$\pi\,(ERS * f_s/2)^2 \;>\; L * H \qquad (1)$$

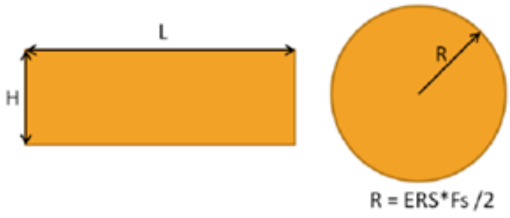

Figure 1. Detection Criteria, Surface of rectangular flaw and disc of equivalent ultrasonic response

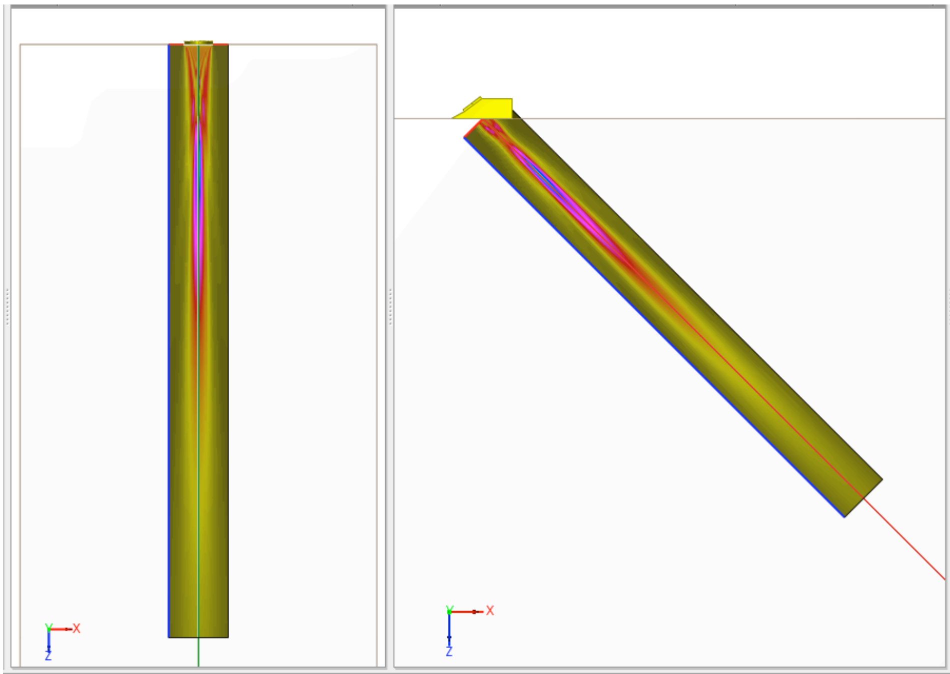

Figure 2. Fields of L0 and T45 transducers, simulated by CIVA

4. Challenge of the PoD approach and its simulation

The computation of the PoD according to experimental data would, based on the number of uncertain parameters, require numerous mock-ups, which would afterwards be destroyed to obtain the real defect dimensions. In the framework of PoD computation, the simulation is particularly cost-saving and time-saving.

CIVA offers several advantages for PoD simulation, such as:

- Fast computations with semi-analytical models;
- Definition of variable parameters, according to statistical distributions;
- Embedded PoD computation tools.

The PoD model embedded in CIVA determines a PoD curve and a confidence bound relying on Berens and Cheng methods using statistical assumptions (see Figure 3).

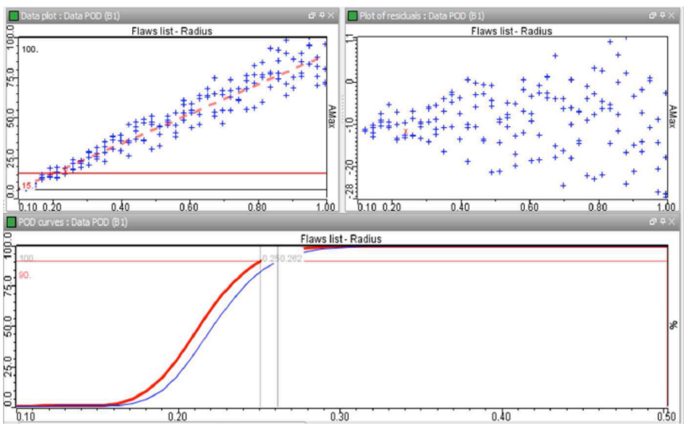

Figure 3. PoD analysis window in CIVA 11

Top left: random response (blue) and linear estimation (dotted red); Top right: residuals
Bottom: PoD curve (red) and confidence bound (blue), classically S-shaped

This approach is based on the standards defined by the US military handbook 1823-A, which is the reference in other industries such as the aeronautical domain. Additional information about the PoD in CIVA is available from [2], [3] and [4].

Meanwhile, in this case, the POD value is given by the formula (1) above, which is not directly implemented in CIVA. Actually, the main issue to compute this PoD is that the results should be expressed in ERS value which is not the unit in CIVA where results are expressed in dB or in % versus a calibration flaw. Manual calculations from simulation results could be done to convert data in the relevant format and compute the PoD as required by ALSTOM Power, but this activity would become tedious and time-consuming due to the numerous calculations involved. Moreover, the PoD needs to take into account the detection of the flaws with all inspections. The methodology currently defined applies to different inspections, such as L0, T45 circumferential or T45 longitudinal. The multi-probe PoD is not the summation of the individual PoDs: it is the ratio of the detected flaw over the total number of flaws, a flaw being "detected" when the detection criterion is obtained for at least one of the inspections, but the whole PoD value does not change if a flaw is detected by one or several transducers.

That is why EXTENDE has developed a specific tool in order to allow an efficient simulation campaign of such PoD with CIVA.

5. Automation of the PoD computation

The computation of the PoD requires following the 4 steps below:

- Reference DGS curves computation
- Simulation of the numerous "random" cases with results expressed in ERS unit according to the calculated DGS curves
- PoD computation for each probe based on the ERS and the detection criteria
- Multi-probe PoD

5.1 DGS curves computation

DGS curves are required in order to determine ERS. DGS curves represent the amplitude responses of FBH of various diameters depending on the FBH depth. It is possible to define manually in CIVA a parametric variation on the FBH depth and diameter but CIVA does not provide any tool to plot the results: the DGS curves should therefore be plotted in any external software. Moreover, in such a variation in CIVA, the scanning step and length are by default the same for all flaws. It means that the scanning steps should be smooth enough to get the maximum FBH response as accurately as possible whatever the FBH diameter and depth and a large scanning pattern need to be considered to inspect over all FBH located in a wide depth range, which leads to long computations.
The tool developed by EXTENDE allows creating easily a CIVA variation in which the inspection zone (scanning step and length) is optimized for each flaw, allowing faster computation. From a nominal CIVA file simulating the inspection configuration (probe, specimen, flaws…), the tool automatically creates a CIVA variation file corresponding to the inspection by the same probe of a parallelepiped block made of the same material

in which is embedded a FBH: a new specimen is defined, the probe is copied and pasted from the nominal configuration and a FBH is automatically embedded. Due to an optimized scanning pattern, the computations are efficient. For example the optimized computation of DGS curves for L0 probe took 2h instead of 22h with a manual definition. After computing the variation in CIVA, the tool finally allows to display the DGS curves.

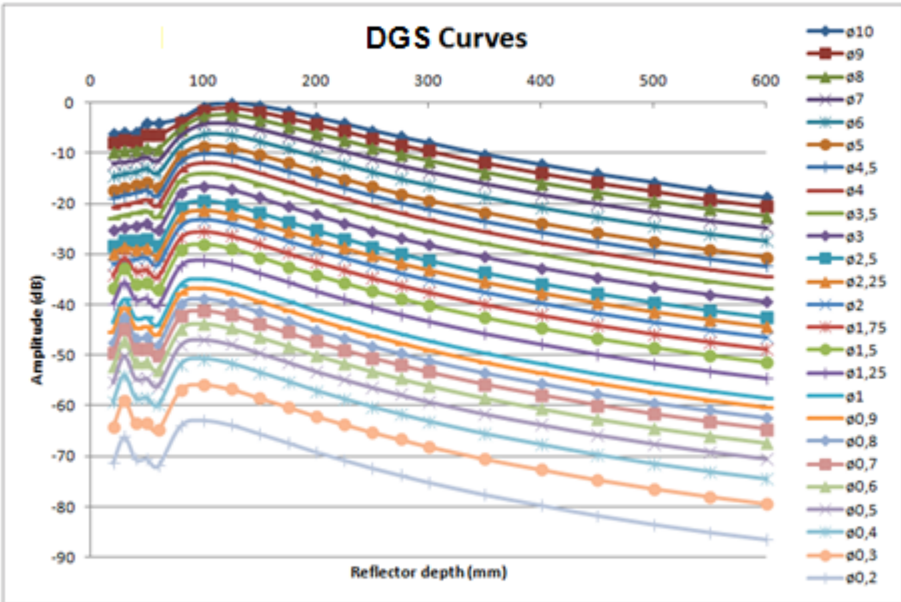

Figure 4. DGS curves computed for several FBH diameters

Table 2. DGS curves computation

Existing Possibilities within CIVA	**Additional features provided to CIVA by the dedicated tool developed by EXTENDE**
Ability to simulate FBH responses with different sizes and depths	Dedicated interface launching DGS curves computation for a range of FBH sizes and depths defined by the user, based on one nominal configuration defined in CIVA
Ability to monitor parametric studies in one set of batch simulations	Automatic plotting of DGS curves
	Automatic adaptation of scanning plan and step depending on the size and depth of FBHs

5.2 ERS computation of the target flaw

The second step consists in simulating the responses of the target flaws (rectangular notches in this case) accounting for a random variability of different parameters as defined in table 1. In order to determine the ERS, the developed tool automatically pick-up the amplitude and the depth of each random flaw and compares it to the DGS reference curves. The FBH response at the notch depth is obtained by a linear interpolation along the depth for each FBH diameter. Then, the flaw amplitude in ERS is determined from another interpolation of the 2 closest DGS curve values assuming that the amplitude variation is linear with the FBH surface.

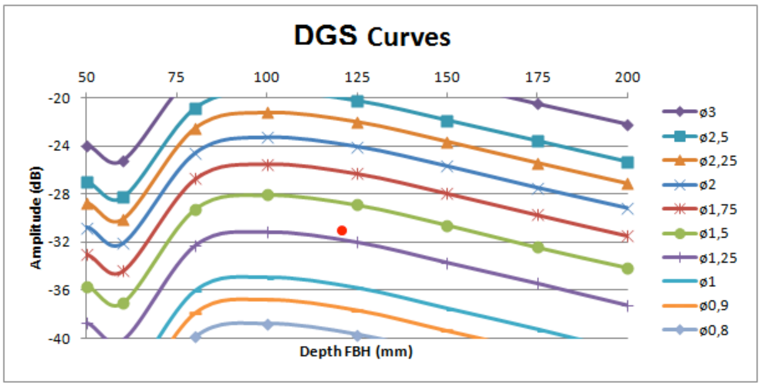

Figure 5. ERS estimation from DGS curves

For example, if a flaw at 121 mm depth gives a response at −31 dB (red point in figure 5), it is plotted between the Ø1.25 mm (purple) and Ø1.5 mm (green) curves. In this case the interpolation gives an ERS of 1.32 mm.

Table 3. Simulating random flaw response and ERS value computation

Existing Possibilities within CIVA	Additional features provided to CIVA by the dedicated tool developed by EXTENDE
Ability to run series of calculation with random variations of selected input parameters defined by statistical distributions	Automatic ERS computation by interpolation from DGS curves Values of the different flaw responses calculated and available in an Excel spreadsheet

5.3 Single Probe PoD computation

For each inspection, the PoD can be expressed as the ratio of the detected flaw over the total number of flaws, the detection criterion being defined in formula (1).
Therefore, the obtained ERS values are processed in order to get the PoDs for all of the individual inspections and for the defined safety factor "fs" coefficient. The PoD is computed dynamically by the PoD tool. For each flaw, the ratio of the previously detected flaws by the number of previously inspected flaws is computed and can be displayed. The results are reliable when the convergence is obtained, which corresponds to the point where the dynamic PoD stabilizes.

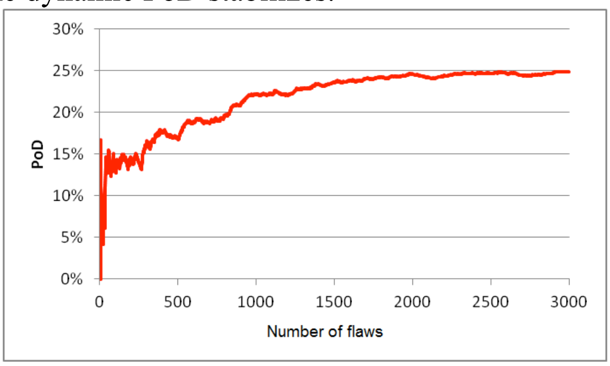

Figure 6. Dynamic PoD for one probe and for a given safety factor *fs*

The dynamic PoD from the previous figure gets stabilized around 24 % after 2000 calculations. Analyzing data with fewer flaws would not be reliable. The PoD can be recalculated for another safety coefficient without re-launching the whole simulation process. This PoD value can look like a weak one, but as mentioned above, the example simulated for the development of this tool assumes that the flaws were arbitrary orientated (uniform probability of orientation between 0° and 180°). For a given application, where the flaw orientation can be defined with a more realistic statistical distribution, the PoD would be much higher with regards to the inspection angles defined.

Table 4. Single probe PoD computation

Existing Possibilities within CIVA	Additional features provided to CIVA by the dedicated tool developed by EXTENDE
PoD curves computation following the BERENS model	PoD value computation along the criteria defined in (1)
Cheng confidence bound	Dynamic PoD to check convergence

5.4 Determination of multiprobe PoD

The determination of multi-probe PoD is not the sum of the PoD of each probe, but the ratio of the flaws detected by at least one inspection by the total number of flaws. Indeed, with this PoD definition, the Multiprobe PoD value will only increase if a new probe allows detecting a flaw that was not detected by the other probes.
As this multiprobe PoD needs to be performed on the same set of random flaws, and as the manual comparison of results from different configurations would be tedious, another part of the tool has been developed.
The tool allows monitoring CIVA in order to run the same set of flaws than the first case with the new probes. The DGS curves corresponding to the new transducers also need to be determined. When the ERS are extracted in each case, the multi-probe PoD can be computed by the tool. Then, individual ERS results are created in a file gathering the information for each flaw coming from the different inspections. Finally, the multi-probe PoD is automatically computed depending on the selected probes and the security factors. The security factors can be adjusted and some of the probes involved can be removed afterwards in order to get instantaneously a new PoD value. Doing that, the influence of each transducer can be directly visualized and its contribution to the flaw detection is easily understood by ticking/unticking it in the multiprobe PoD computation process.

Table 5 Multiprobe PoD computation

<table>
<tr><th>Existing Possibilities within CIVA</th><th>Additional features provided to CIVA by the dedicated tool developed by EXTENDE</th></tr>
<tr><td rowspan="2">Run several PoD computations for various transducers, the variable parameters being randomly selected from a statistical distribution</td><td>Repeat a similar PoD scenario done for one probe for a new set of probes (i.e. with the same values for the random parameters).</td></tr>
<tr><td>Automatic update of the PoD value based on a selected set of probes allowing to identify the influence of each probe on the whole PoD</td></tr>
</table>

5.5 Application example

The influence of the addition of another probe on the Multi-Probe PoD has been checked on this case. For example, the single probe PoD of the T45° circumferential inspection is quite weak compared to both L0° and T45° longitudinal inspections. However, it slightly increases the multi-probe PoD meaning that most of the flaws detected by this inspection were not detected by the other inspections.
Additional inspections can be considered to determine the optimum number of inspections in order to obtain a good PoD in a minimum time.

6. Conclusion

An assessment of the detectability of flaws (Probability of Detection) in critical components needs to be performed in most industrial sectors. In the context of PoD, numerous mock-ups are generally necessary to obtain reliable statistical data. Efficient simulation helps saving time and cost, which is why CIVA can be particularly useful in this case and well-suited thanks to the fast semi-analytical models. Additionally, CIVA also has the ability to run series of calculation with random variations of input parameters based on statistical distribution in order to compute PoD data. As the PoD value required by ALSTOM Power relies on specific detection criteria, based on flaws response in ERS unit, EXTENDE has developed a dedicated tool which monitors CIVA efficiently and automatically in order to ensure the PoD computation based on the ALSTOM criteria, whether it be for a single probe or a multi-probe inspection set.

ALSTOM is now able to determine by simulation the optimal number of inspections allowing obtaining a convenient multi-probe PoD using the dedicated tool developed by EXTENDE.

References

1. S. Mahaut, S. Chatillon, M. Darmon, N. Leymarie and R. Raillon, “An overview of UT beam propagation and flaw scattering models integrated in the CIVA software” Review of Progress in QNDE, these proceedings (2009).
2. F. Jenson, E. Iakovleva and N. Dominguez, “Simulation Supported POD Methodology and HFET validation case” Review of Progress in QNDE, these proceedings (2010).
3. M. Carboni, S. Cantini, “A Model Assisted Probability of Detection” approach for ultrasonic inspection of railway axles” in the proceedings of WCNDT 2012
4. N. Dominguez, F. Jenson, Ph. Dubois, F. Foucher, “NDT performance demonstration using simulation” in the proceedings of ASNT 2012