

# CIVA Modelling for Pipeline Zonal Discrimination

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## Abstract

The technique of inspecting pipeline girth welds using zonal discrimination has been used extensively since the late 1980s. Refinements in the past decade have included the introduction of phased-array equipment, improved sizing algorithms, developments for small diameter pipe and techniques for exotic alloys, to mention a few.

Until recently, inspecting pipeline girth welds using zonal discrimination has not taken advantage of modelling in the same way as other applications. Simple ray-tracing software has provided a good means for operators to calculate probe positioning and focal law limitations for coverage; however, the effects of flaw characteristics and focusing parameters has not been studied with modelling in the same way it has in the power generation applications.

This paper looks at the use of the analytical modelling software called CIVA as a tool to investigate many of the issues facing pipeline AUT.

**Keywords:** Phased-array, zonal discrimination, ultrasound, modelling, CIVA

## 1. Introduction

Pipeline girth welds have been routinely inspected using automated ultrasonic testing (AUT) with zonal discrimination since the late 1980s. Its development and advantages are well documented (1,2,3,4,5,6,7).

As the 21st century was entered elaborate systems were put in place to codify the use of AUT (8, 9)... e.g. OS-F101 ASTM E-1961). These included requirements for the expectations for calibrations and quantitative statistical and probabilistic assessment of performance. Codified methodology was based on what was considered feasible with the equipment of the day. This approach was empirical and based on thousands of observations of calibrations and macro photos of flaws removed from welds, generally as part of system qualifications.

One of the first real attempts to use modelling to improve the technology came with the efforts to reduce the lateral beam spread in the zones (10, 11 e.g. <http://www.ndt.net/article/wcndt2008/papers/82.pdf>). This used PASS (Phased-array Simulation Software) to model the lateral beam size that would result with elements curved in the passive plane.

More recently the use of Finite Element Modelling (FEM) has been introduced to better illustrate and understand the principles involved in ultrasonic inspection in general. AUT has benefitted from this work in that the concepts common to other weld examinations can be extrapolated to pipeline AUT (12).

Some industries (in particular nuclear power generation) have established formal methodologies for validating inspection techniques. Performance demonstration requirements are part of ASME Code, Section XI, Appendix VIII (13) and in Canada and Europe, the European Network for Inspection and Qualification (ENIQ 14) is the preferred method for qualification of NDE inspection systems (procedures, equipment and personnel). Both of these documents make provision that at least some of the demonstration use computer modelling to augment the technical justification of the inspection techniques. With the heavy dependence on realistic mock-ups in the DNV OS-F101 requirements for qualification, there seems to be potential that this process could be augmented by suitable modelling if it could be demonstrated to be representative of the real conditions. Fabricating a series of flaws in a mock-up with well controlled skew, tilt, ligament variation and vertical extent, is not possible in real life. However, if a model could be shown to accurately represent a known flaw, then confidence could be had for small variations in varying some of the parameters on that flaw.

In this paper the analytical software CIVA (15) is used to illustrate not only the main principles of the zonal discrimination technique, but also to indicate the ability to aid in predicting sizing and signal characterisation with flaw parameter changes.

## **2. CIVA Software**

CIVA UT module is a simulation software tool that includes beam pressure modeling, beam propagation and its interaction with flaws or specimens. It allows simulating a whole inspection process (pulse echo, tandem or TOFD) with a wide range of probes, components, and flaws. Calculations are made to predict signals including backwall echo, surface echo, corner effects and shadowing.

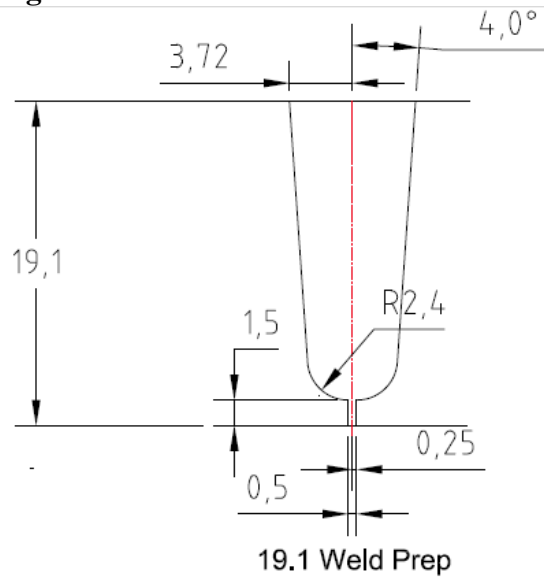
CIVA is used in a variety of industries and the veracity of the models is validated in specific validation sessions. The designer of CIVA (CEA) participates each year in the Benchmark session of the QNDE conference in the United States.

## **3. Zonal Calibration Simulation**

The technique of Zonal discrimination as used in pipeline girth weld inspections divides the vertical cross-section of a pipe weld bevel preparation into zones with heights determined by the bevel shape. Targets are placed in a section of pipe that allow the beams to be directed at each “zone” and the response from these targets is optimised with the added requirement that the targets from the adjacent zones not produce a response greater than half that of the main zone target. Typically the subsurface targets are flat bottom holes (2-3mm diameter) and the inside and outside surfaces use surface notches.

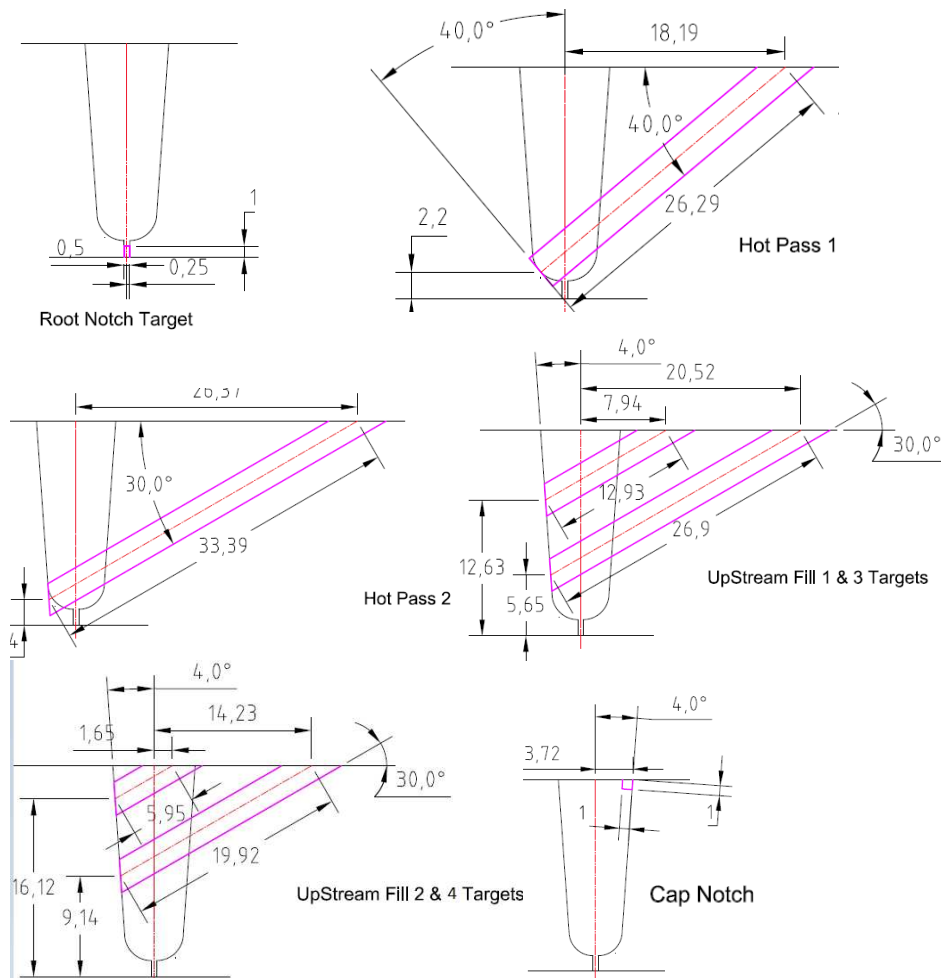
To demonstrate the simulation capabilities of CIVA for the zonal technique, a project example was selected that was qualified to DNV OS F101 Rules. This project used pipe with a 42” diameter (1067mm) and a wall thickness of 19.1mm. The J-bevel is illustrated in Figure 1.

**Figure 1 19.1mm wall J-Bevel**



Calibration targets and their positions along the face of one side of the bevel are illustrated in Figure 2.

**Figure 2 Zonal Targets for the 19.1mm wall J-bevel**



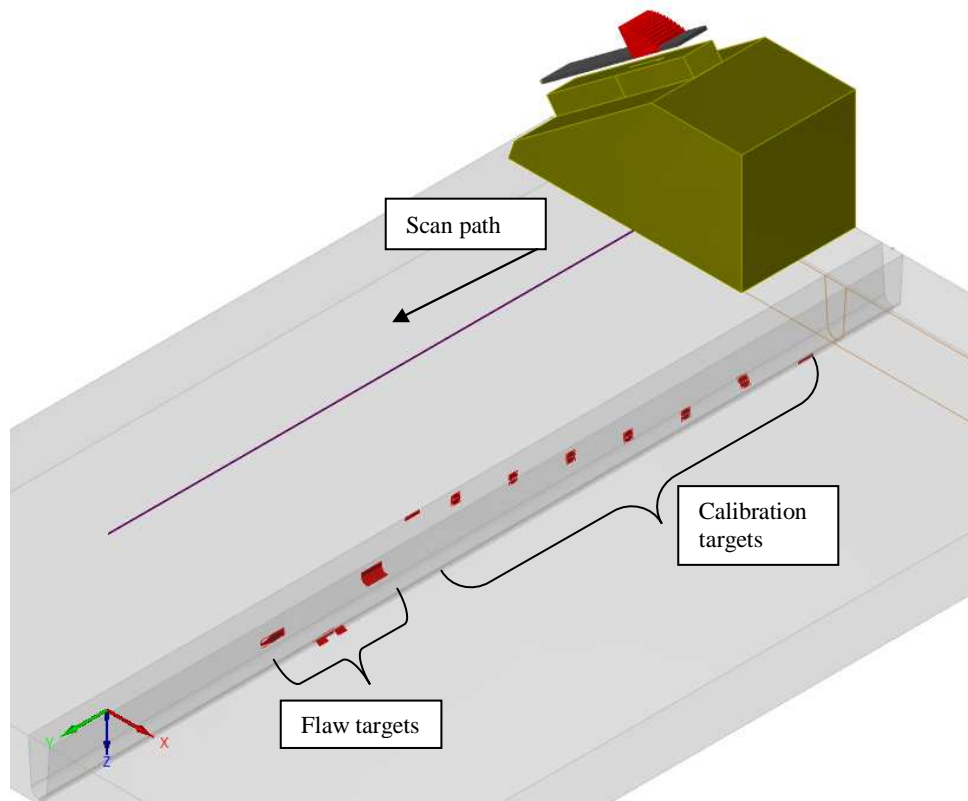
The process of validating the modelled scans against the realities of the pipe and welds involved two signal comparisons;

- Calibration responses
- Flaw responses

CIVA allows the user to construct 3D components with embedded targets. Therefore the first step was to construct the weld bevel in CIVA and place targets that duplicated the position and shape used in the steel. Minor simplification approximations were used. A flat 19.1mm wall was modelled instead of a 42 inch cylinder section and the irregularities of the weld root and cap were omitted and only an extruded 2D profile was used to achieve the 3D solid model. Since the probe wedges used in inspections are always contoured to the surface the differences attributable to curvature would be negligible on a diameter of 42 inch.

Three candidate flaws were located in the selection of flaws that had been salami sectioned for the qualification. Flaw profiles were constructed using the CAD features of CIVA based on macro photo images made at each of the weld locations. Flaw dimensions and exact orientations were obtained from the photos. The flaws made in the CIVA CAD were then placed in the CIVA CAD-constructed weld profile in the same elevations as identified in the macros. So as to make direct comparisons with the calibration targets the flaws were placed in the same modelled component as the calibration targets. The calibration targets and flaws used for the modelling are illustrated in Figure 3.

**Figure 3 Calibration and Flaw targets**



Focal laws were then prepared in the CIVA software for a probe that was identical (pitch, frequency, element size, wedge angle, etc.) to that used to generate the real scan.

A table of the parameters used in the actual scan and those used to obtain the calibrations in CIVA are compared in Table 1.

**Table 1 Comparison of CIVA and Real Focal Law settings**

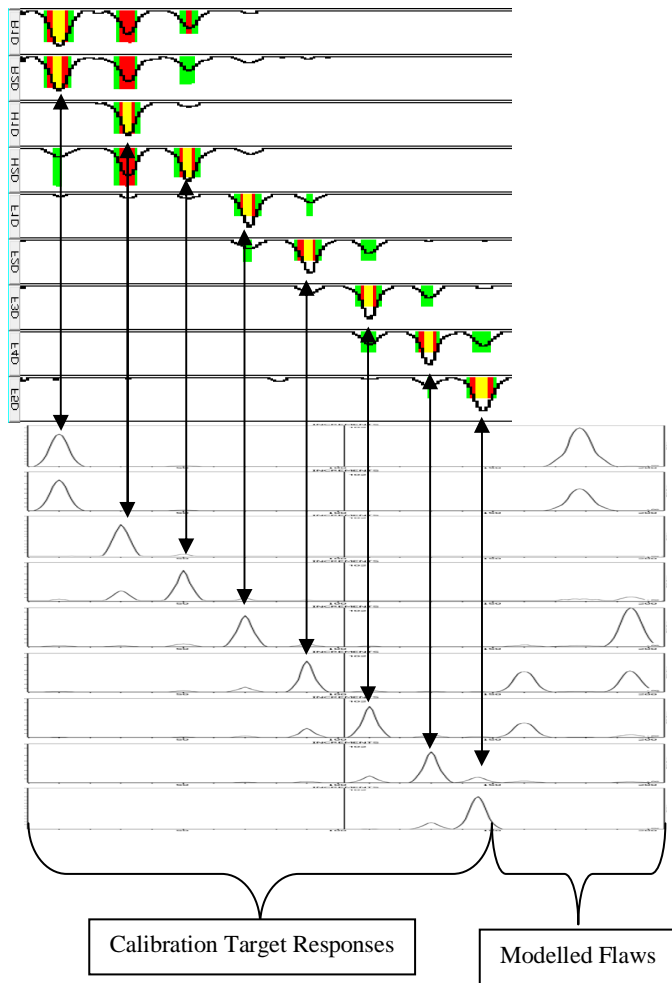
Zone/Channel	Number of Elements		Start Element		Angle(s)	
	Real Scan	CIVA Scan	Real Scan	CIVA Scan	Real Scan	CIVA Scan
Root 1	16	16	41	41	55	55
Root 2	24	24	23	26	65	65
Hot Pass 1	16	16	43	42	50	50
Hot Pass 2	16/16	16/16	42/38	42/38	50/58	50/58
Fill 1	12/12	12/12	41/44	40/44	50/58	50/58
Fill 2	12/12	12/12	43/11	41/11	45/53	45/53
Fill 3	12/12	12/12	40/15	41/15	45/53	45/53
Fill 4	12/12	12/12	37/18	37/18	45/53	45/53
Fill 5	16	16	16	17	55	55

The only differences between the modelled and real scans are therefore the start elements used. Some differences can be expected between the ideal drawing positions and the variations on the machined position from the drawing position. Unlike the flaws that were sectioned the calibration targets were assumed to be within the required tolerance range of machining.

Comparison of the actual scan calibration to that obtained by the CIVA simulated calibration is accomplished by setting the target responses in the simulation to 80% screen height.

Subsequently the responses from the modelled flaws can then be compared to the actual responses. Figure 4 illustrates the calibration scan and is compared to the simulated scan that includes the modelled flaws.

**Figure 4 Comparing Real and Modelled Calibration Scans**



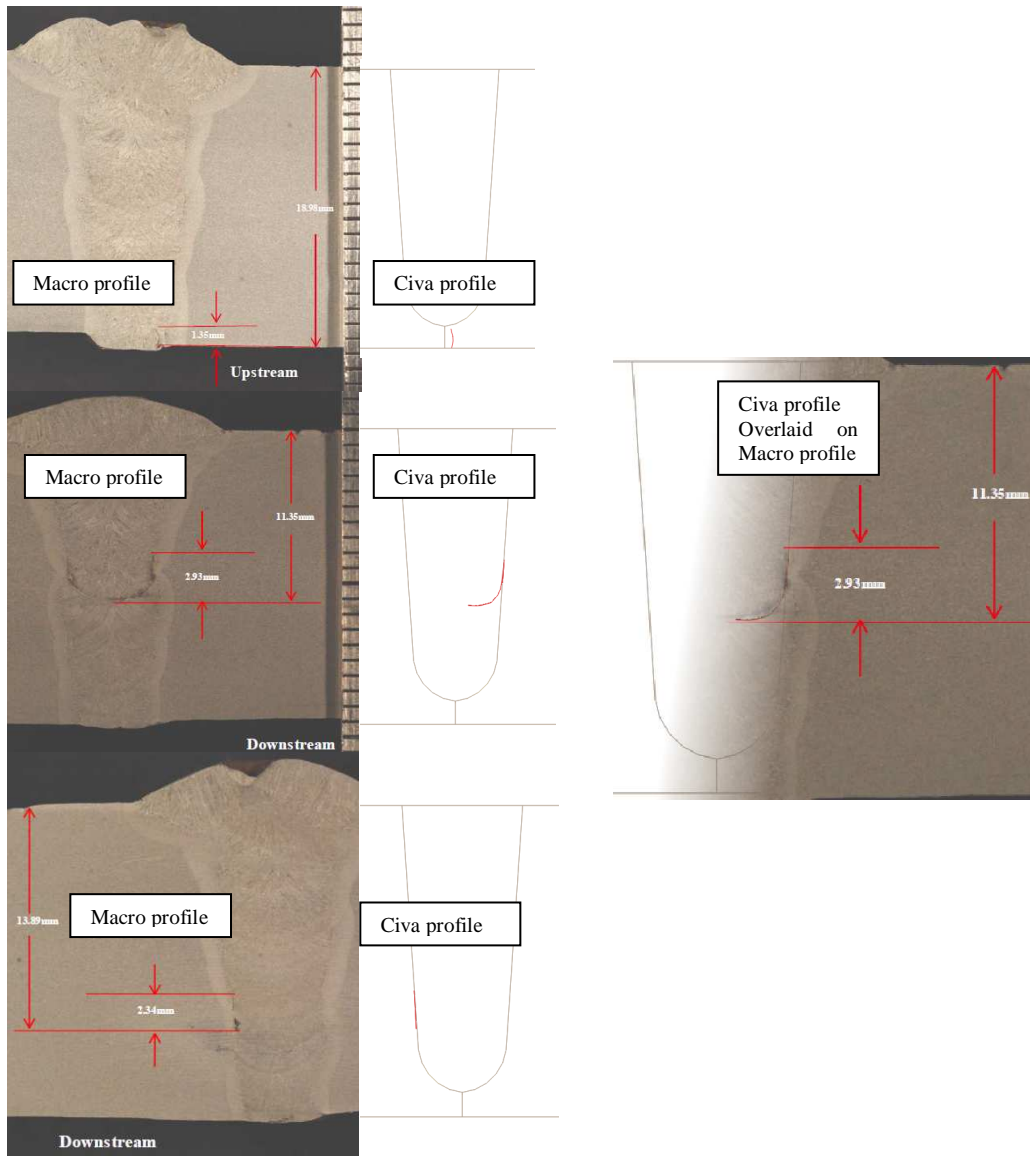
Arrows indicate the zone targets seen in the real and simulated scans. Faint tip echoes seen in the actual scan are not all identified in the simulation. The simulation uses the Kirkoff model whereas the tip echoes would require the GTD (general theory of diffraction) model which is not available for interactions after the skip.

#### **4. Flaw Simulations**

Flaws selected for the modelling were generally short (<15mm) and effort was made to reproduce the main details of the cross sections seen in the macro photos. Full duplication of all facets and surface irregularities of the flaws is not possible with CIVA tools; but neither is a full knowledge of the flaw available when sampling with salami cuts at 2mm increments.

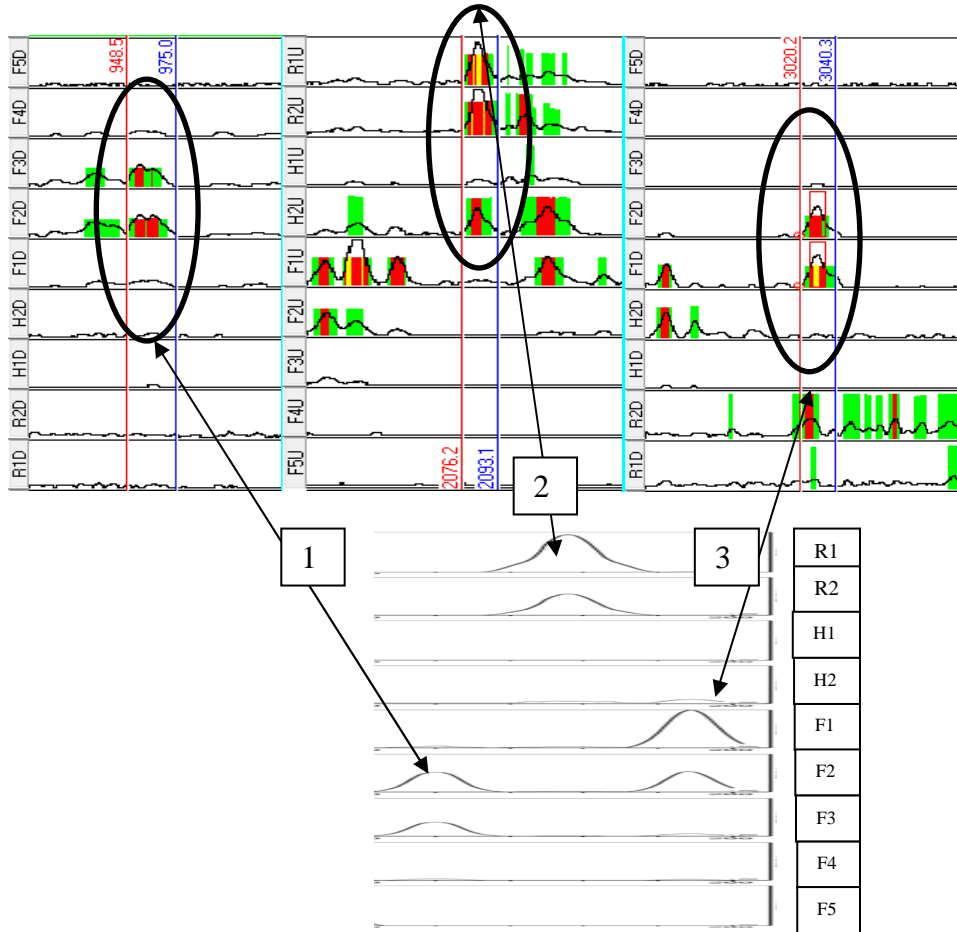
Close approximations were made and compared to the photos using image overlays. These are illustrated in Figure 5.

**Figure 5 Comparing Flaw Photo Images and Flaw Models**



Scans of the modelled flaws were run simultaneous with the modelled calibration scans (as seen in Figure 4). Strip chart section of the scan results images from the real flaws were extracted and compared to the simulations. See Figure 6.

**Figure 6 Comparing Flaw Scan Images and Flaw Models**



Of primary concern for “detection” of indications is the amplitude over evaluation threshold. Amplitude responses in the “main channels” was made for the real and simulated flaws and recorded in Table 2.

**Table 2 Comparing Flaw Amplitudes**

Flaw	Zone	Real Scan Amplitude (% screen height)	CIVA Scan Amplitude (% screen height)
1	F2	49	52
	F3	49	39
2	R1	95	95
	R2	100	61
3	HP2	8	13
	F1	73	94
	F2	69	56



With the exception of R2, all the main responses of the simulations are within 2dB of the real flaws. As noted earlier, not all aspects of the flaws can be reproduced in the model so variations are to be expected.

## 5. Running Scenarios

Having demonstrated that the CIVA simulations of the calibration and main flaw responses represent good approximations of the real conditions provides some confidence in the modelling process.

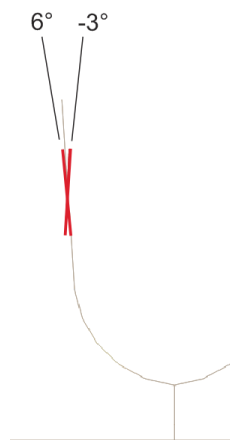
Having demonstrated confidence in the main features where comparison to the real situation can be seen, the next step is to use the simulation tools to vary parameters. Examining the effects of flaw variation using real welded samples and macros can be a very costly and slow process as the library of experience is built up. With the reluctance of most companies to share experience the lessons learned are not likely to be part of the general knowledge of AUT operators.

CIVA allows the user to run simulations that change one or more parameters to examine the effect on results. Tilt, skew, shape, length, height, ligament, etc. are all possible to vary in an incremental fashion using "scenarios". This can assist in the assessment of the limits to which the technique can be used.

## 6. Scenario Examples and Their Results

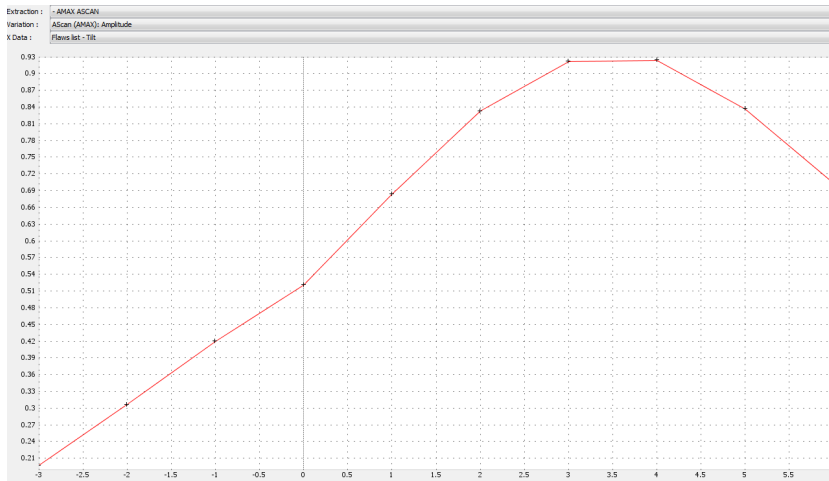
Running "scenarios" allows the analyst to vary one or more parameters and monitor the results. As an example, this was done for Flaw 3 which was the side-wall nonfusion flaw that was seen between Fill 1 and Fill 2 zones. The flaw was initially configured with a tilt of  $3^\circ$ . A scenario was run where the tilt was varied from  $-3^\circ$  to  $6^\circ$  (i.e.  $\pm 3^\circ$  from that used for the construction of the strip chart simulation. Figure 7 indicates the range of tilt used in the scenario.

**Figure 7** Flaw 3 Tilt Variation



The scenario was run to obtain the maximum amplitude at each angle in increments of  $1^\circ$  steps. Upon completion the software provides the signals and a plot of the amplitude variation with the varying parameter (Figure 8).

**Figure 8** Flaw 3 Tilt Variation Amplitude Plot



The plot indicates that the amplitude will remain at a maximum for up to  $1^\circ$  from the modelled condition (i.e.  $3^\circ$  to  $4^\circ$  tilt) but drops to 75% of maximum at  $6^\circ$  and down to about 50% of maximum at  $0^\circ$  (vertical).

## 7. Conclusions

Pipeline AUT has been demonstrated to be feasibly simulated using analytical modelling methods. This suggests that pipeline AUT can take advantage of analytical modelling in a similar fashion to that of ultrasonic technique technical justifications described by ENIQ methods. This could present opportunities to use modelling to augment demonstrations on mock-ups with seeded flaws and use the software to provide model-assisted PoD computations.

Since all sound paths in the normal zonal discrimination technique use bounces off the near or far surfaces, Civa simulation software is limited to the Kirkoff model. This will limit the simulations to just the main pulses (i.e. not the weak off-axis tip diffracted signals).

Analytical modelling of the pipeline AUT has been demonstrated to be useful for;

1. explaining principles
2. a classroom instruction tool
3. optimising beam characteristics (focusing in the active and passive planes)
4. examining the effects of flaw position and size on apportioned amplitude sizing
5. running scenarios on flaw characteristics

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