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Next Generation Technology for Pipeline AUT TFM/FMC

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Abstract
Since the late 1980s automated ultrasonic testing of production welding on pipeline (AUT) has been the preferred NDT method. The technique that has proven to be the most efficient in way of data acquisition, analysis and accuracy, has been termed the zonal discrimination technique. Until recently, no other technique provided the speed required to keep up to the production rates possible by automated welding. With the advent of phased-array technology and faster computers, a new approach is feasible that can augment or even replace the older zonal technique. This paper describes how the Full Matrix Capture (FMC) and Total Focussing Method (TFM) have advanced to provide superior displays and analysis tools for production pipeline weld inspections. Examples are provided illustrating ease of setup, simplicity of analysis and sizing capabilities. The technique is applicable to a wide range of wall thickness and may offer an alternative to the use of the complex calibration blocks associated with the zonal discrimination technique.

Keywords: AUT, pipeline, FMC, TFM, ultrasonic

1. Introduction

NDT on production welding of pipeline girth welds has been in relatively common use since the late 1980s [1,2,3,4,5]. The technique developed around the concept of dividing the weld into vertical increments (zones) and directing beams of ultrasound at the centre of each zone. This technique has led to a standardisation of the process where its critical parameters are formally described [6,7].

The great advantage of the zonal technique has always been the speed with which acquisition and analysis can be achieved. In the girth weld production environment, all aspects of production fit into relatively short (5-10 minute) cycles. The NDT examination process must then also fit into this system with a similar cycle time so as not to slow the production speed (unless repairable defects are detected).

2. Principles of FMC and TFM

Over the years since phased-array techniques have become popular in NDT, the ability to transmit and/or receive at the discrete points formed by the elements along the phased-array probes has provided analysis options not known earlier. Transmitting from each element individually while simultaneously receiving on all of the other elements has been reported in the NDT literature as early as 2004 [8, 9, 10]. At that time it was variously called Inverse Wave Extrapolation (IWEX) or Sampling Phased-Array (SPA).

In the Civa simulation software, a description of the acquisition process is nicely illustrated. There it is termed Full Matrix Capture (FMC). This is seen in Figure 1.

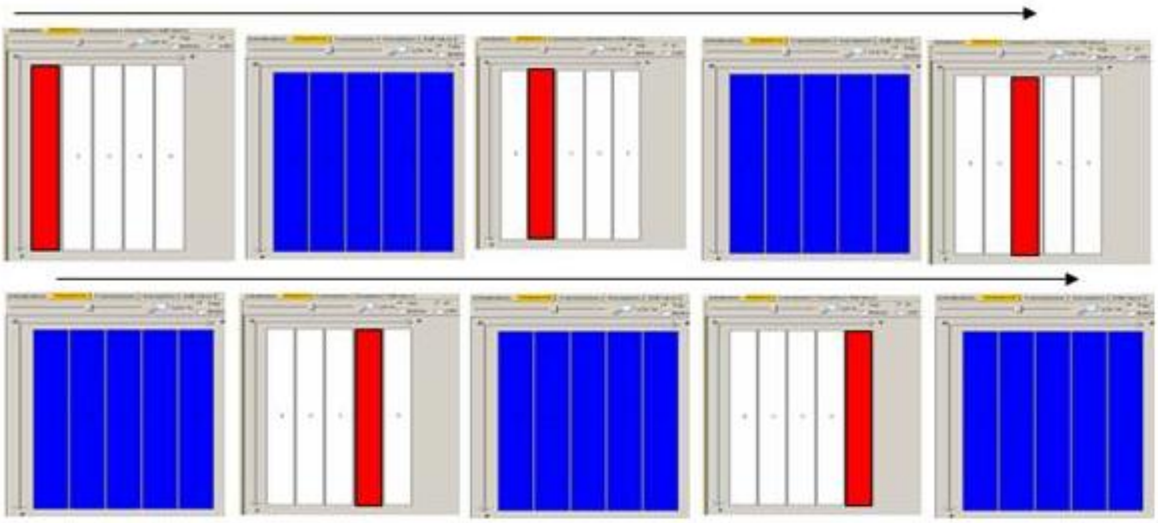
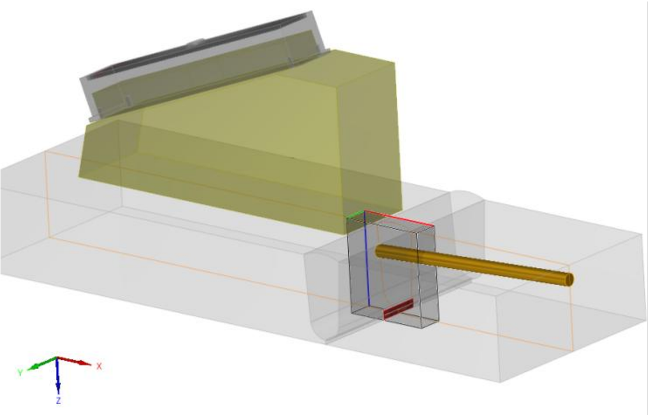


Figure 1 Sequence of firing (red element) and receiving (blue elements) for Full Matrix Capture. (courtesy Civa Simulation Software Help file). Each channel of the transducer will successively transmit and all channels receive.

However, the technique is not actually completed by simply collecting the returned signals along all of the receivers (after transmitting on each of the elements). This is not clear from the earlier names applied to the technique. In fact, the data collected from a single pass of a sequence over a flaw is virtually useless as an analysis image. Figure 2 indicates a setup with 2 fabricated targets; a 2x10mm notch and a 3mm diameter FBH. These are placed in a 20mm thick steel plate with a weld bevel outlined to indicate their relative positions simulating natural defects.

An FMC scan is done at a single position centred at the targets using a linear array probe (60 elements 1mm pitch 7.5MHz) on a refracting wedge intended to produce a natural refracted angle of 65° L-mode. The relative probe position and flaw location are indicated above and the received signals are illustrated as a B-scan-type display below.



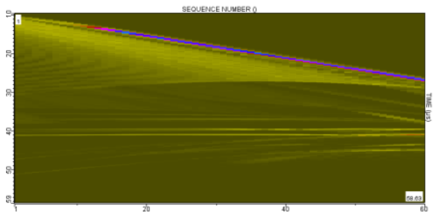


Figure 2 FMC collected results for 60 element probe on a refracting wedge

The unprocessed data display is meaningless to the analyst. A complex vector processing of waveform data must be completed prior to the rendering of a useful signal display. This is a complex vector assembly of waveforms. In order to make sense of the vector additions, the software must be instructed which modes and paths will be used to assemble the collected A-scans into a useful image.

The operator must instruct the assembly algorithm which mode to use, whether or not to use a direct path from the probe to the volume or if skips are to be considered off the far and/or near surfaces. This process of reconstruction of the collected A-scans into an intelligible image has been termed Total Focussing Method (TFM) in the Civa modelling terminology.

When the optimum combination of mode and skip-path are used, the TFM results can provide a useful image. Figure 3 illustrates the processing using direct L-mode for both forward and return paths applied to the setup illustrated in Figure 2. The image on the left in Figure 3 is the basic TFM reconstruction and this is zoomed and overlaid on the targets in the simulation on the image to the right in Figure 3.

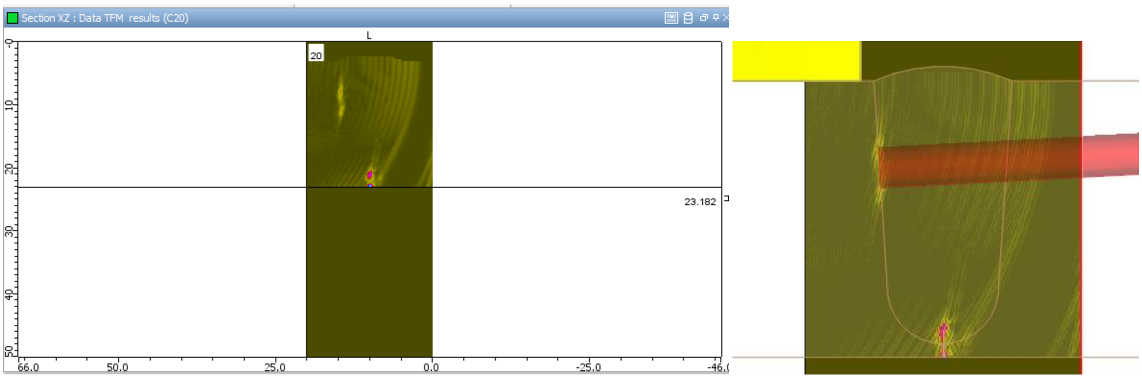


Figure 3 TFM using Direct L-Mode on both forward and return paths (zoomed image on right overlays TFM reconstruction over the target image)

The authors have used Civa simulations extensively in the development of the techniques developed for pipeline girth weld applications. Therefore, the separation of acquisition (FMC) and data processing (TFM) as described in Civa have been maintained as the separate functions (FMC and TFM) in this paper.

3. Adaptation of FMC/TFM to pipeline Girth Weld Inspection

Pörtzgen in 2004, compared his IWEX technique to other display formats including TOFD and strip-charts and suggested some advantages compared to the other techniques; however, he provided no actual data displays. The earliest application of FMC/TFM on pipeline girth welds seems to have been described by Deleye [11] as recently as 2012. They made comparisons of their IWEX results to the traditional TOFD, strip-chart and sectorial scan presentations. At the UZDM conference in St. Petersburg (Russia) in 2013, Volf [12] made a presentation demonstrating a pipeline girth weld system that can combine all of the FMC/TFM technique with the same hardware as the traditional zonal method. Volf's presentation indicated that a system was available offering an add-on software module to increase the capabilities of the pipeline AUT system.

Pipeline AUT systems have come a long way since the early version in the 1980s and 1990s where 20 to 30 monoelement probes could be found on a scanning head. Phased-array systems are now much less bulky and typically consist of a pair of phased-array probes plus dedicated TOFD and/or dedicated probes to detect transverse flaws.

The first images produced by Deleye [11] were seen as separate items isolated from the TOFD and strip chart displays. Yet these displays are also useful. In addition to developing optimised algorithms for TFM, Eclipse Scientific has been developing a variety of displays for various clients. Details of the weld geometry (wall thickness, bevel angle) can make one TFM algorithm superior to another. Volume coverage and detection afforded by TOFD and pulse-echo methods may be helpful in understanding where signals may be attributable to geometric features that might cause false calls.
Assembling imaging layouts that provide rapid identification of flaws and their dimensions is critical in reducing analysis time and increasing sizing accuracy. To this end, the displays

developed in the combined zonal/TOFD/TFM system can be customised to the client's project requirements.

There is a great risk in collecting so much data that the operator is required to spend critical time going through multiple displays. Depending on the wall thickness examined, scanning rates of 50mm/s to 100mm/s can be achieved by most AUT systems using the standard zonal discrimination technique with strip-chart displays. Recent developments of the AUT system that incorporate FMC and TFM with improved algorithms and faster computer processor speeds, scanning rates of 25-30mm/s have been achieved.

Due to the anisotropic nature of even the regular carbon steel pipe used for pipeline production, it has been necessary to manufacture project specific calibration blocks for the zonal technique. These blocks are made with a variety of targets with particular care to ensure that the flat bottom faces align with the ideal bevel preparation and are each centred at precise depths. In these anisotropic steels, acoustic velocities can differ significantly as the angle of refraction changes. Property variations requires the calculation of velocities at several angles so that delay laws can be configured to accurately place the focussed beam at each zonal target.

Since the FMC process uses the omni-directional nature of the wavelets generated off each element, it is not attempting to steer and focus the beam to a specific location. If used as a stand-alone technique, FMC could be configured with a much simplified calibration block.

When used as a stand-alone technique, the calibration of sensitivity on an FMC setup can be simplified to a single through hole. Figure 3 illustrates how the uniformity of sensitivity can be set using a simple through slot (5x1mm) and 1x10mm cap and root notches. This is illustrated in Figure 4.

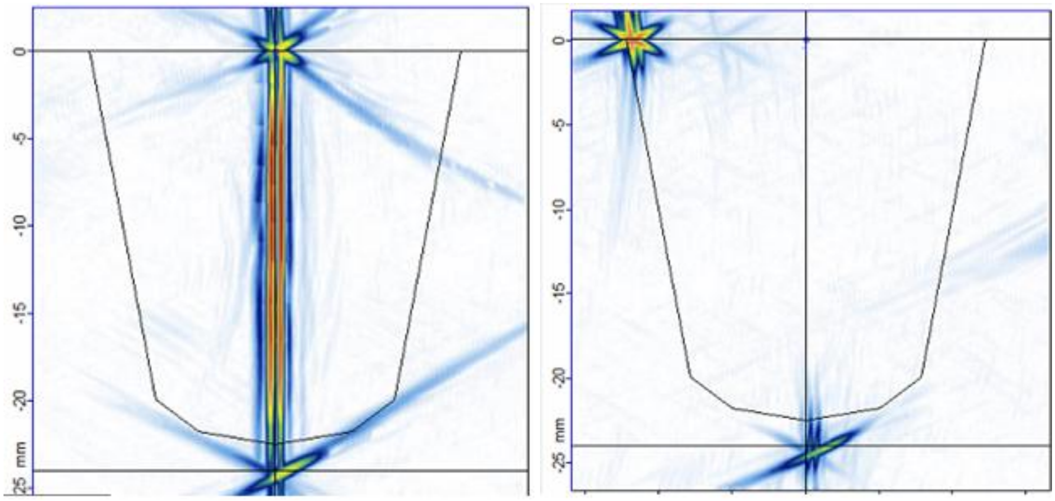


Figure 4 FMC/TFM sensitivity calibration. Slot (left) and cap and root notches (right)

Since the process used by FMC uses only the arcs of the wavelets from each element, the need of pulse-echo techniques for long standoff positions to inspect thick sections can be reduced. Figure 5 illustrates the positioning of an FMC probe and that of a pulse-echo zonal setup to examine a narrow-gap weld in 50mm wall thickness.

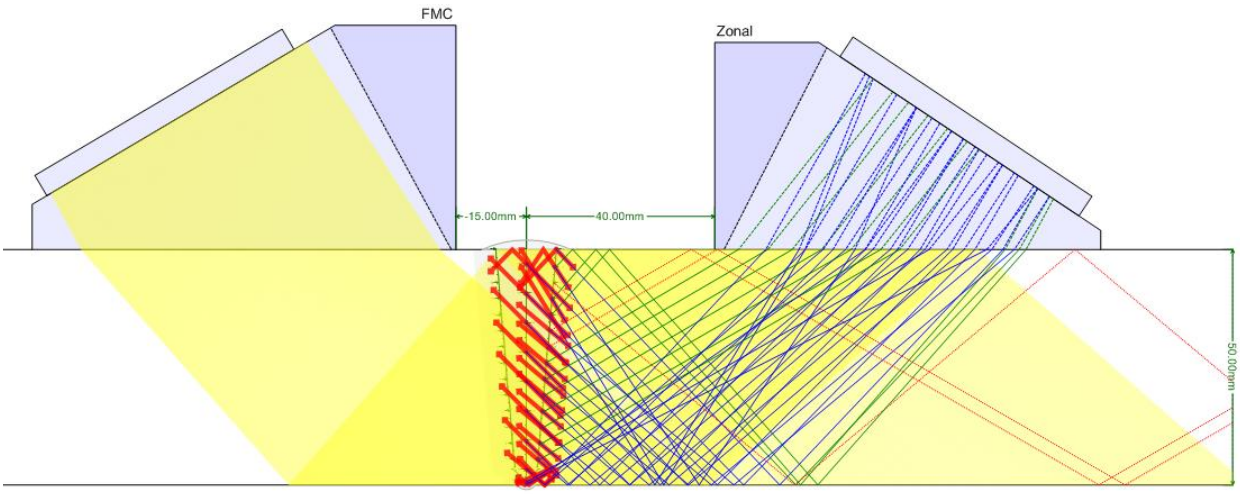


Figure 5 Comparing probe standoffs for FMC and zonal technique

In the development work carried out by Eclipse, FMC/TFM was used in parallel with other standard AUT techniques (zonal discrimination with strip-charts, TOFD and B-scans). This meant that the performance of the FMC/TFM could be compared directly to the detections and sizing of the standard techniques when both were used on the zonal discrimination calibration block.

4. Example Application

To illustrate some of the features of FMC/TFM, an example is provided in which the FMC data was acquired with the same phased-array probes in the same stand-off positions used to acquire the standard zonal data. Standard zonal data includes amplitude and time data for strip chart displays, B-scans for detection of volumetric features such as porosity, and TOFD.

4.1 25mm wall thickness J-bevel

Narrow-gap GMAW (gas metal arc welding) is a preferred process in pipeline girth weld production. A typical weld preparation uses a J-bevel with a small angle in the fill region.
This section illustrates some of the displays available in the TrueView system that provide enhanced imaging of the calibration and examination results that incorporate the FMC data on a GMAW weld. The weld is configured for a pipe with 36 inch diameter and 25mm wall thickness.

Figure 6 illustrates the zonal calibration block layout designed in Beamtool.

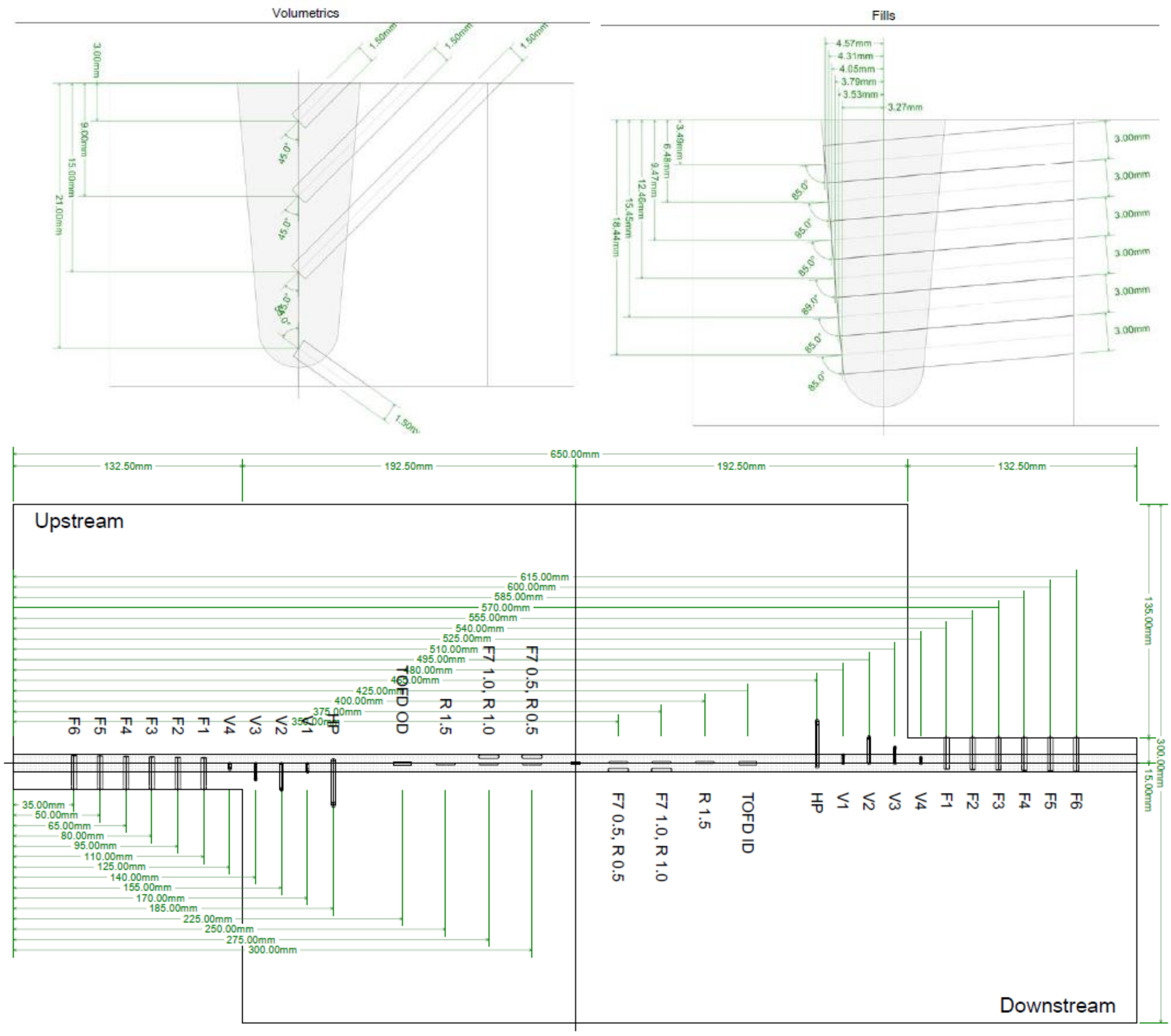


Figure 6 25mm J-bevel zonal calibration block (Beamtool output). Weld profile cross-section (above) and target layout along simulated weld length (below)

Zonal calibration is typically displayed on a "strip-chart" style of plot that indicates response amplitude and time in a gated region for each zone along the length of the scan. Figure 7 illustrates the typical zonal display with B-scans, TOFD and coupling status added to the strip-chart data.

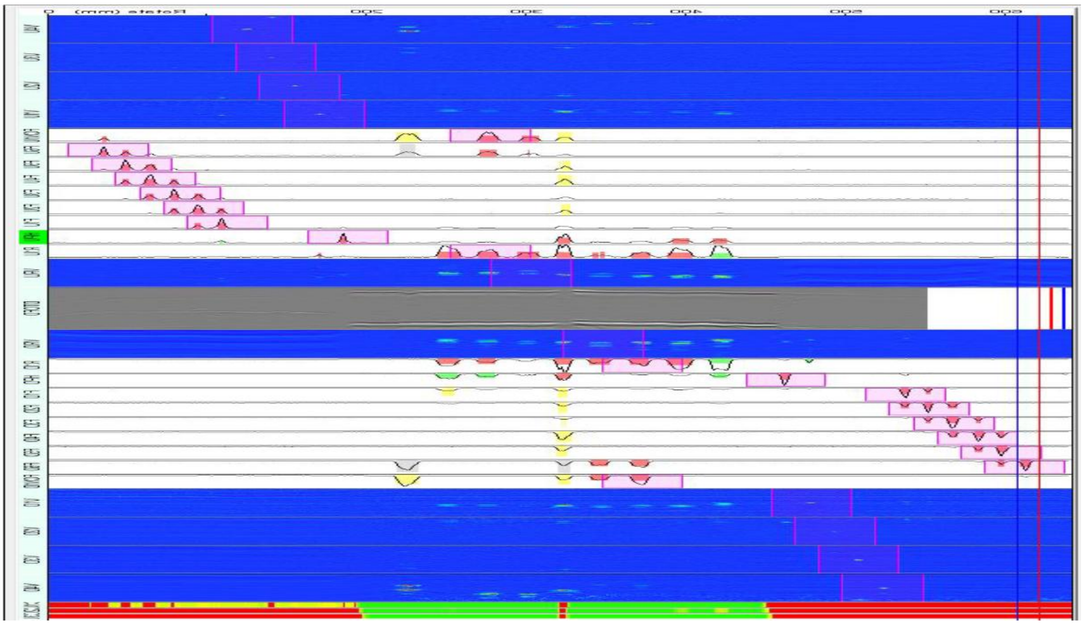


Figure 7 25mm J-bevel zonal calibration scan

The zonal calibration scan is relatively easy to analyse once the operator has had suitable training and experience. However, analysis of the strip-chart data still requires some interpretation skills. The addition of a TFM display provides a much more intuitive presentation. Essentially, the data display is seen using the Top-Side-End view as used by a CAD designer.

The TFM display allows for ease of flaw location in three dimensional space and also provides options for flaw sizing using simple beam boundary techniques or tip echo techniques. An algorithm previously developed for strip chart size estimates can be applied to the TFM results. Similar to “segmentation” used in Civa, the algorithm groups signals that come from the same defect or part of a defect.

Figure 8 compares the scan results from the TFM reconstruction in Top and Side views and the typical strip chart display to the calibration block design for the downstream side of the targets. Instead of multiple strip charts to analyse and apply sizing estimates to, the TFM display presents an intuitive display of detections within the specified volume.

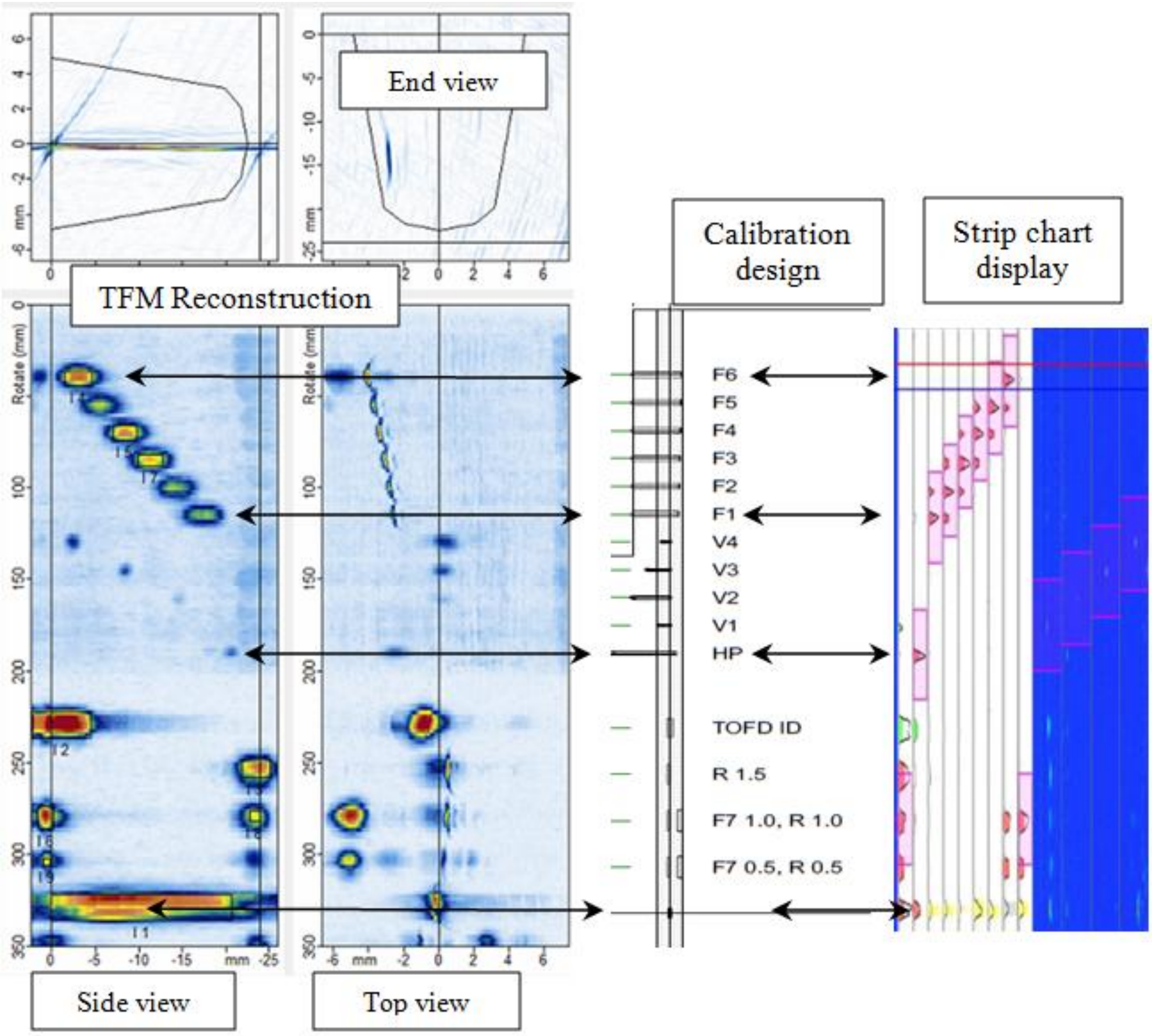


Figure 8 TFM displays of zonal calibration block scan compared to strip chart display and block design drawing

When the system is suitably configured for sensitivity, results of the weld examination can be displayed with easy-to-interpret Top-Side-End views. Figure 9 illustrates a section of weld with welding defects located. In addition to the Top and Side views, the End view has been added on the left side. The End view incorporates a weld-bevel overlay that can be used to locate the indications relative to the ideal weld profile.

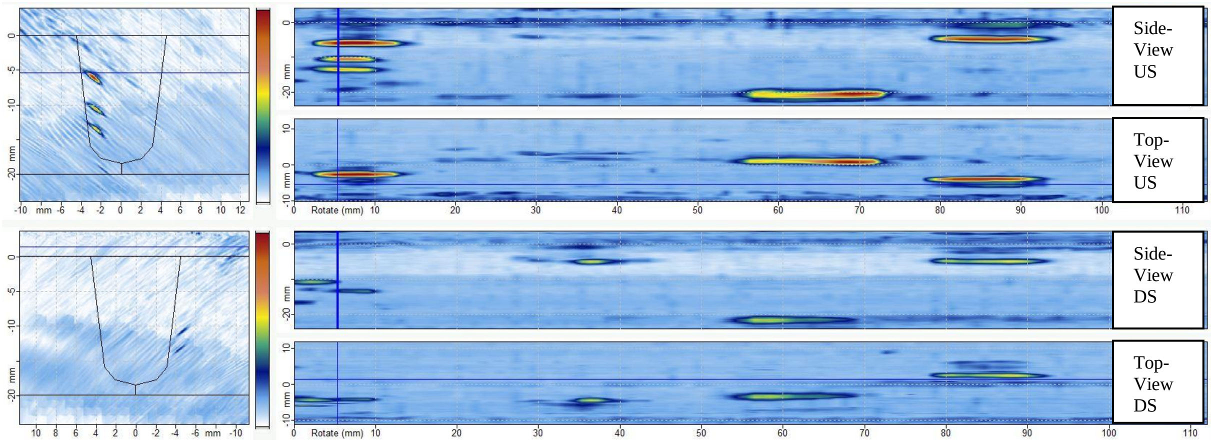


Figure 9 TFM view of weld examination

In Figure 9 there are 3 nonfusion flaws seen in the UpStream (upper half) Side view at the blue vertical cursor. They have close vertical spacing. This is typical of a stacked defect associated with multiple starts and stops at the same location.

Pulse-echo techniques and TOFD techniques do not have the ability to resolve the indications due to beam-overlap, in the case of pulse-echo scans, and due to ring-time dead zones in the case of TOFD. However, TFM can significantly improve the resolution of vertically stacked indications and provide an effective tool to apply fracture-mechanics interaction rules.

Figure 10 compares the TOFD and pulse-echo results from the stacked flaw to the TFM presentation. Pulse-echo imaging cannot resolve 3 separate indications. And although TOFD can detect 3 main arcs associated with the indications, the lower tips cannot be resolved for useful vertical sizing. The TFM image can be used to estimate flaws heights and ligaments. Starting from the top, the 3 indications can be estimated as having heights of 1.8mm, 1.4mm and 1.3mm with ligaments between them of 2.5mm and 0.9mm.

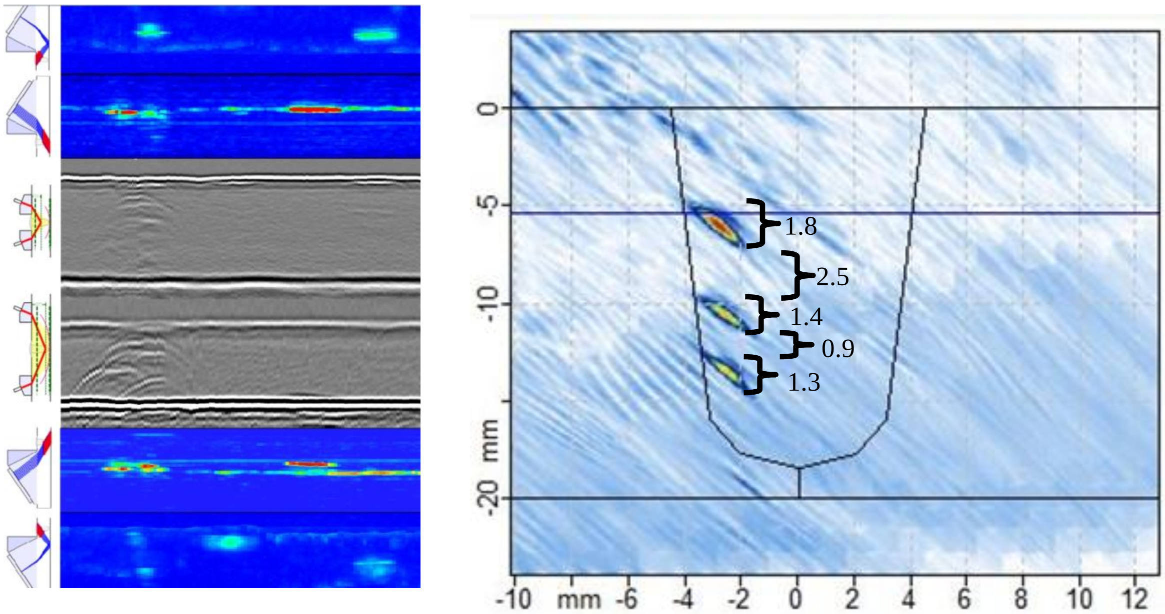


Figure 10 Comparing resolution detail of pulse-echo and TOFD to TFM

5. Conclusions and Comments

Several advantages can be achieved using the new FMC/TFM AUT system. This includes;

- Improved detection and sizing for sub surface indications.
- Improved resolution of ligaments for ID and OD subsurface indications
- Improved resolution of “stacked” indications
- Potential to inspect welds without a calibration block or with a much simplified calibration block compared to zonal techniques
- Top-Side-End view display provides an easily interpreted representation of the weld volume with potential for 3D imagining
- Relatively thick sections can be examined without resorting to long standoffs or very large probes
- Ability to use the same hardware setup for both zonal and FMC data acquisition thereby providing opportunity to use both techniques on the same weld
- Potential to inspect a weld with an unknown weld profile (such as would occur for repair areas) without extra calibration requirements

Use of FMC and TFM as a supplement or replacement to standard zonal techniques on production girth weld inspections using AUT is now viable. Processing algorithms and improved computing speeds can provide production speeds capable of the cycle times required in the production environment.

The apparatus used for the acquisition of the images in this paper was the TrueView system developed by Eclipse Scientific. FMC and TFM capabilities added to the system are in addition to other displays (standard zonal, TOFD and pulse-echo) and software features such as InspectionBank (database software for production and documentation tracking), Beamtool (with zonal and FMC configuration modules for procedure development) and STATUS-5 (probability and statistical analysis software for system qualifications).

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