AUTOMATED EVALUATION FOR TOFD

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ABSTRACT

Ultrasonic examination with Time of Flight Diffraction (ToFD) technique is widely used during construction, e.g. weld examination, but can also be applied for in-service inspection, like detection and sizing of root corrosion/erosion. Wall thicknesses typically vary from 6 mm (pipes) to over 200 mm (heavy wall vessels). Advantages of ToFD are direct height sizing capabilities and data storage for future reference.

The evaluation and interpretation of ToFD data is performed by the operator, supported by software tools (like hyperbolic cursors, depth calculations). The evaluation and interpretation is labor intensive especially when multiple indications are present or when many measurements need to be performed, e.g. remaining wall thickness in the case of root corrosion/erosion.

This paper will discuss a novel approach using dedicated algorithms to remove intrinsic effects of the measurements such as the hyperbolic tails of indications and the source signature. This is performed by applying multiple signal processing techniques such as Inverse Wave field Extrapolation (IWEX) and Sparse Spike Deconvolution (SDD) techniques. The parameter settings for the developed algorithms are optimized for each ToFD data set with minimum operator interaction. The resulting image represents the actual shape and position of defects and also has a higher contrast. The output data, with easier defect recognition and sizing, can be evaluated by the operator but is especially suitable for automated evaluation, decreasing evaluation time. In this article the approach and first results are presented.

INTRODUCTION

The principle of the Time of Flight Diffraction (ToFD) technique is well known (fig. 1). Developed in the UK in the seventies [1] ToFD is now a widely accepted NDT technique, both in new construction and In Service NDT. Various studies have been conducted to evaluate its performance in terms of detection and sizing capabilities [2, 3]. European standards for its use as well as acceptance levels for indications found with ToFD have been developed [4, 5, 6] and several national schemes for qualification of ToFD operators are in place.

Similar to radiography, the interpretation of ToFD images is mainly based on the ability of the operator to recognize typical patterns. Similar to other NDT techniques, operators need a certain level of training in order to be able to reliably detect and accurately size defects. Although signal amplitude, together with noise level, is important for the visibility of relevant signals in the ToFD

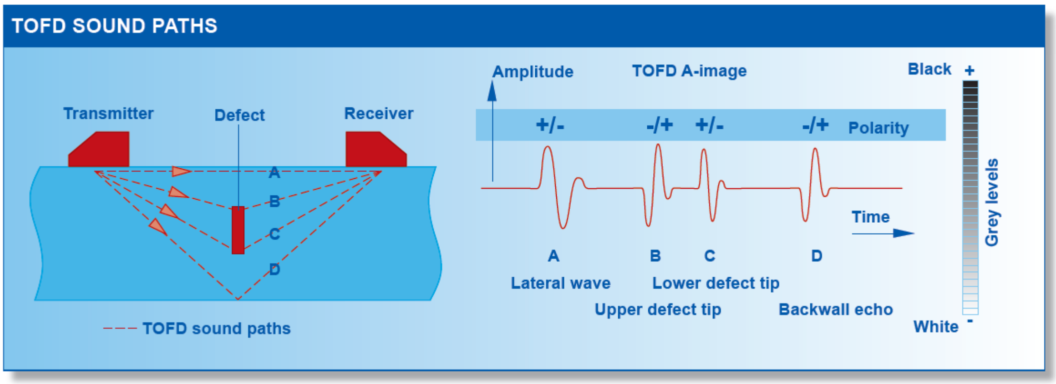


Fig. 1: Typical ToFD setup and response

image, it is not directly used as a parameter for defect detection and characterization. Recognition of signal phase however is relevant for the operator to maximize sizing accuracy. The way how signals appear in a ToFD image (fig. 2) is strongly influenced by factors such as ultrasonic frequency, resolution, beam spread (causing typical hyperbolic tails to the indication) and the presence of noise (random noise and material scatter). Defect nature affects signal phase (diffractions from upper and lower boundaries of an imperfection have opposite phases). The resulting ToFD image is always a combination of the actual defect characteristics **and** the ultrasonic behavior intrinsic for a ToFD examination. The operator is trained in dealing with these aspects, and has software tools at his/her disposal to support interpretation (hyperbolic cursors, lateral wave removal, lateral wave straightening, contrast enhancement etc.).

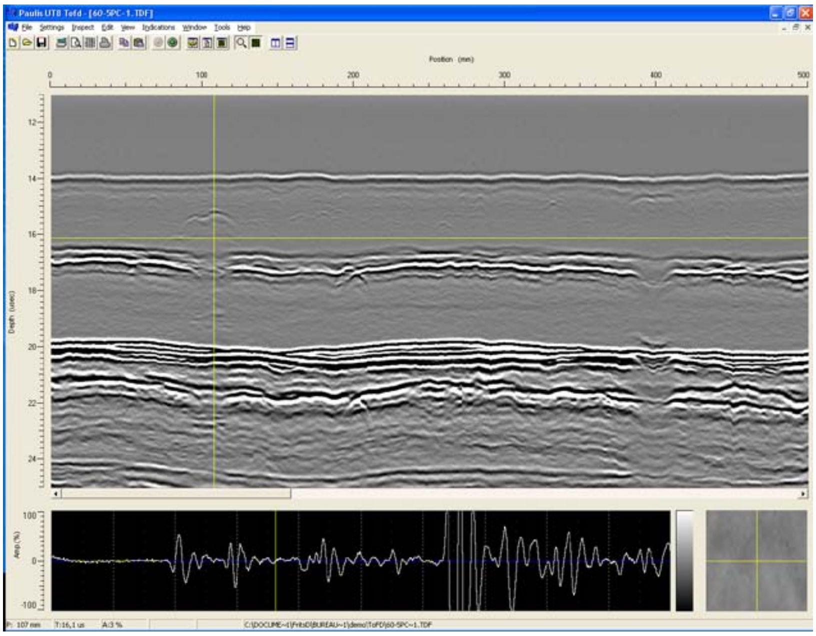


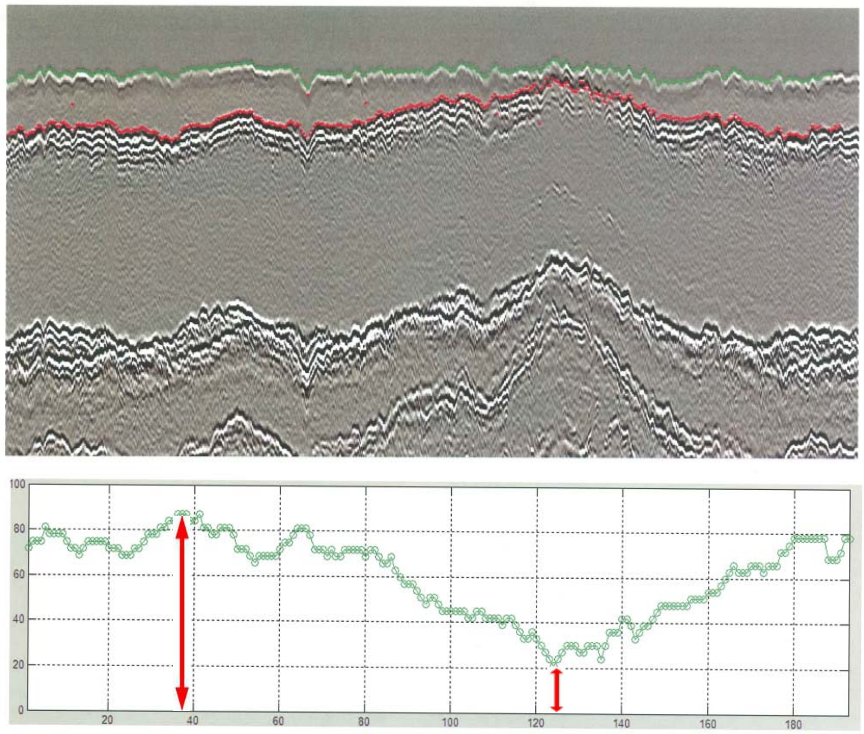
Fig. 2: Example of a ToFD image. The vertical cursor marks an indication

Although trained operators are able to do this, interpretation may be time consuming and affected by the human factor. Because of this, it could have significant advantages to process ToFD data in such a way that intrinsic effects are automatically removed by the software, making interpretation much more straightforward and, as a further step, introduce automatic interpretation.

TOFD IMAGE PROCESSING

In the past, several attempts were taken (by Applus RTD and others) towards automated interpretation of ToFD images. Such approaches were usually based on algorithms mimicking interpretation by an operator and were partly based on the use of neural networks. Although such algorithms exist [7], automated interpretation remained difficult because relevant signals are not always clearly visible between noise and small insignificant artifacts, such as gas pores.

An application where a simple image processing for automated interpretation could work is detection and quantification of root corrosion and erosion with ToFD. Fig. 3 shows a typical ToFD image obtained in such an exercise. Using the ToFD image (bitmap) as a basis, the contour of the backwall echo (marked red in the top figure) is automatically detected and its time of flight at any point along the weld compared to the time of flight of the lateral wave (green line, top figure). This allows for an accurate display of the remaining wall thickness as a function of position along the weld, see the lower figure.



Lateral wave

Backwall

Arrows show maximum and minimum wall thickness

Fig. 3: Automated evaluation of root corrosion [arbitrary units]

However, such an approach will only work if no disturbing factors are present in the image, such as indications of weld imperfections. Such factors would disturb the evaluation. Smoothing can help, but only to a certain extent. To deal with these limitations, the work described in this paper is not using image processing, but data processing. The idea is to apply data processing first, making interpretation of the image easier and more straightforward, and then consider automated interpretation of the improved image.

TOFD DATA PROCESSING

Steps that can be taken in data processing to obtain an improved image are mainly directed to the improvement of resolution, both in lateral direction (horizontal resolution in the ToFD image) and in depth (vertical resolution in the ToFD image). Various tools can be used to achieve this:

- Zero phasing (removes phase of the pulse on input data)
- Normal move out (simulates coinciding source and receiver positions)
- Wave theory (IWEX[1], imaging of defects in linear depth)
- Inverse move out (convert back to actual source/receiver travel time)
- Sparse Spike Deconvolution (replaces pulse shapes by spikes).

As an example, a synthetic ToFD image as shown in fig. 4 is taken as a benchmark data set. It contains short indications with no length such as pores, relevant indications with some length and noise.

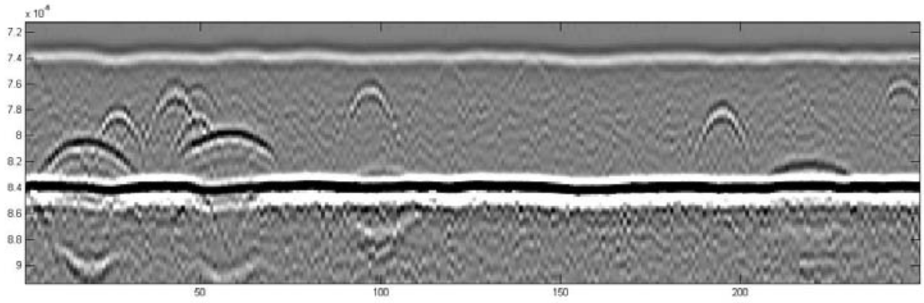


Fig. 4: Synthetic benchmark data set (input data)

As a first step, Normal-Move-Out correction is used. This step simulates zero offset between source and receiver. As a result, the vertical axis is linearized. The resulting signals are displayed in the image shown in fig. 5. Note that the lateral wave is strongly stretched in time now. This clearly shows that ToFD has poor resolution near the scanning surface [1].

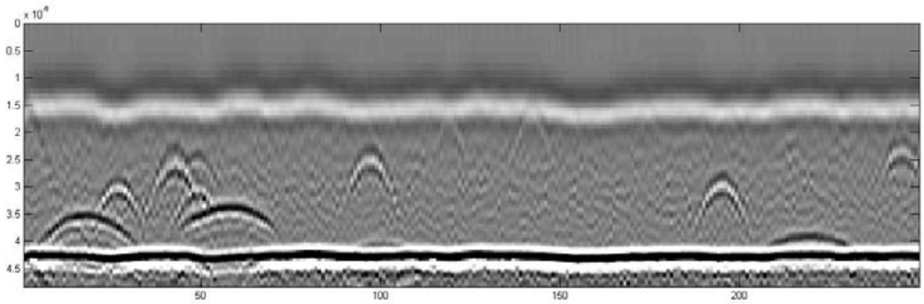


Fig. 5: Normal-Move-Out correction

[1] Inverse Wave field EXtrapolation, developed by Applus RTD and Delft University of Technology for imaging of weld defects using phased arrays [8]

The use of IWEX as a data processing step collapses the diffraction curves of the pores (defects with no length) in the horizontal direction (fig. 6). In vertical direction we clearly see the pulse shape. As a result of this processing step, the indications with length (which still have a hyperbolic shape even after processing) now show their true length, whereby the effect of beam spread has been removed.

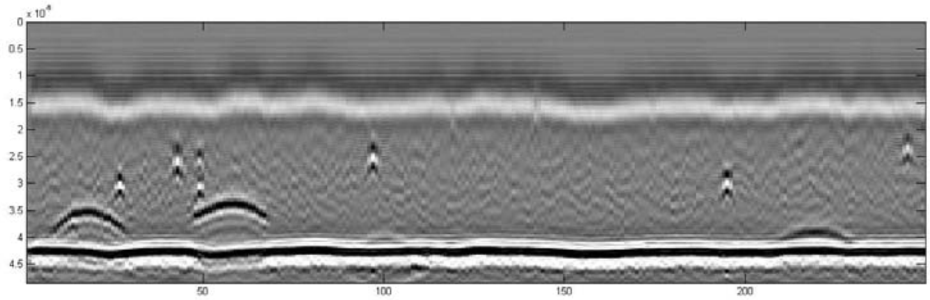


Fig. 6: Imaged Zero-Offset data (IWEX)

Next, in order to remove the stretch near the lateral wave, the data set is transformed back to true source to receiver travel times. As a result, we now see undistorted pulse shapes throughout the section (fig. 7).

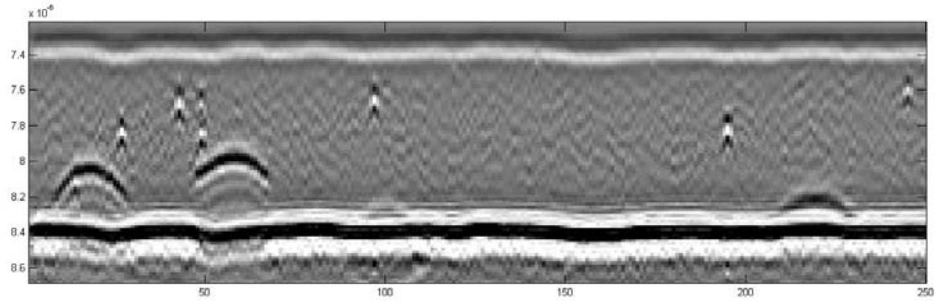
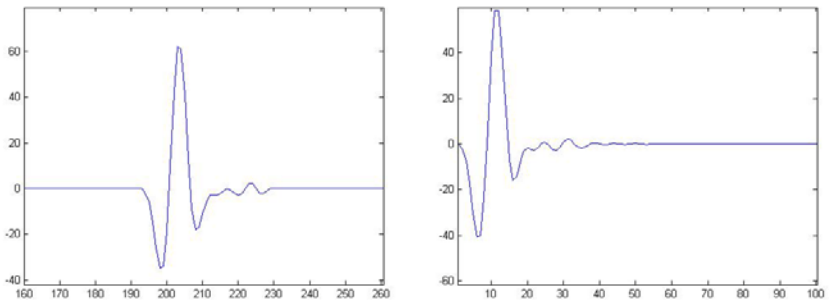
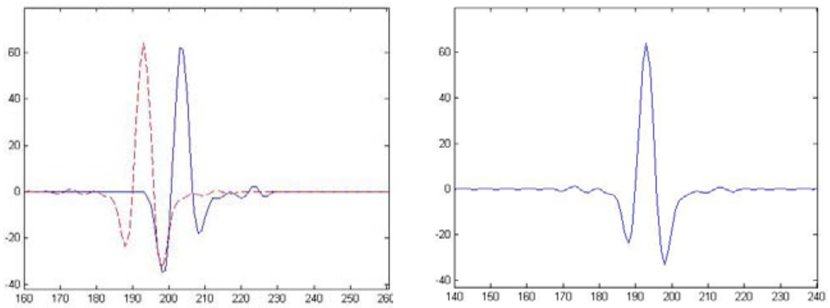


Fig. 7: Imaged data with true source receiver spacing restored

As a next step, zero phasing can be applied. If the input pulse is known, it can be transformed to a symmetric shape where maximum amplitude occurs at the true trigger moment of the pulse. Of course the result is no longer a causal pulse, but this is not a problem because it is used only in the computer as a means for more accurate and unambiguous measurement of pulse timing (fig. 8).



A: Lateral with floating time *B: Minimum phase equivalent*



C: Zero-phasing *D: Minimum phase subtracted from input*

Fig. 8: Zero phasing

The impact of zero phasing on the ToFD image can be seen in fig. 9. Zero-phasing of the data, either on the input or on the true time converted output, can be used. This gives maximum energy at the actual location of the defect and a symmetric pulse shape around that.

Note that there is a small time shift (vertical direction) between the zero-phase image (fig. 9) and the non-zero phased (minimum phase) image (fig. 7). Because this applies to all signals, time distances between signals (relevant for defect sizing) remain unaltered.

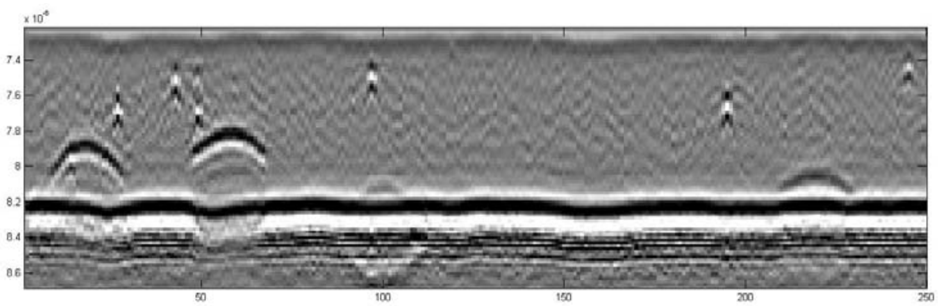


Fig. 9 Zero-phase image

SPARSE SPIKE DECONVOLUTION

The Sparse Spike Deconvolution process aims at removing the pulse shape from the image altogether. Everywhere where the process recognizes a pulse shape it replaces it with a spike.

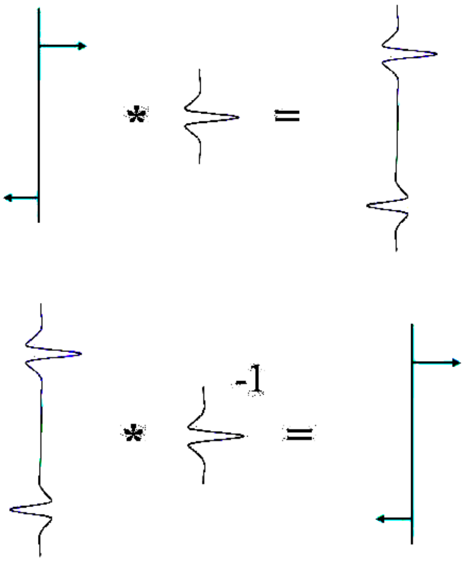


Fig. 12: Convolution (top) and Sparse Spike Deconvolution (bottom)

This process will only work if one knows beforehand that relatively few indications are present on any given signal. Fig. 12 top shows how the actual signal consists of spiky indications convolved with the source pulse. The deconvolution process applies the inverse pulse shape to the signals to obtain the spiky indications (fig. 12 bottom). For stabilization of the deconvolution algorithm the sparseness assumption is essential.

Fig. 13 (lower image) shows the image of fig. 9 after application of sparse-spike deconvolution.

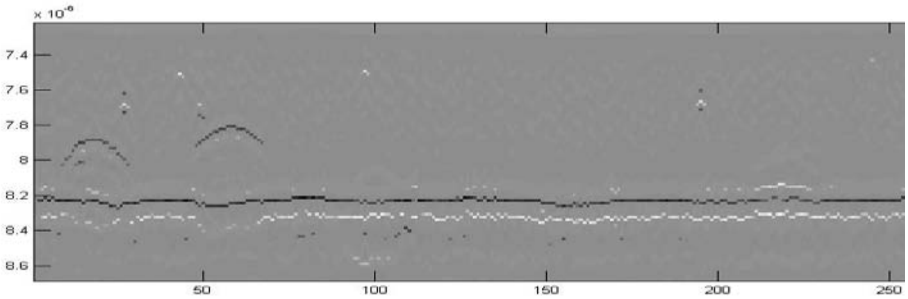
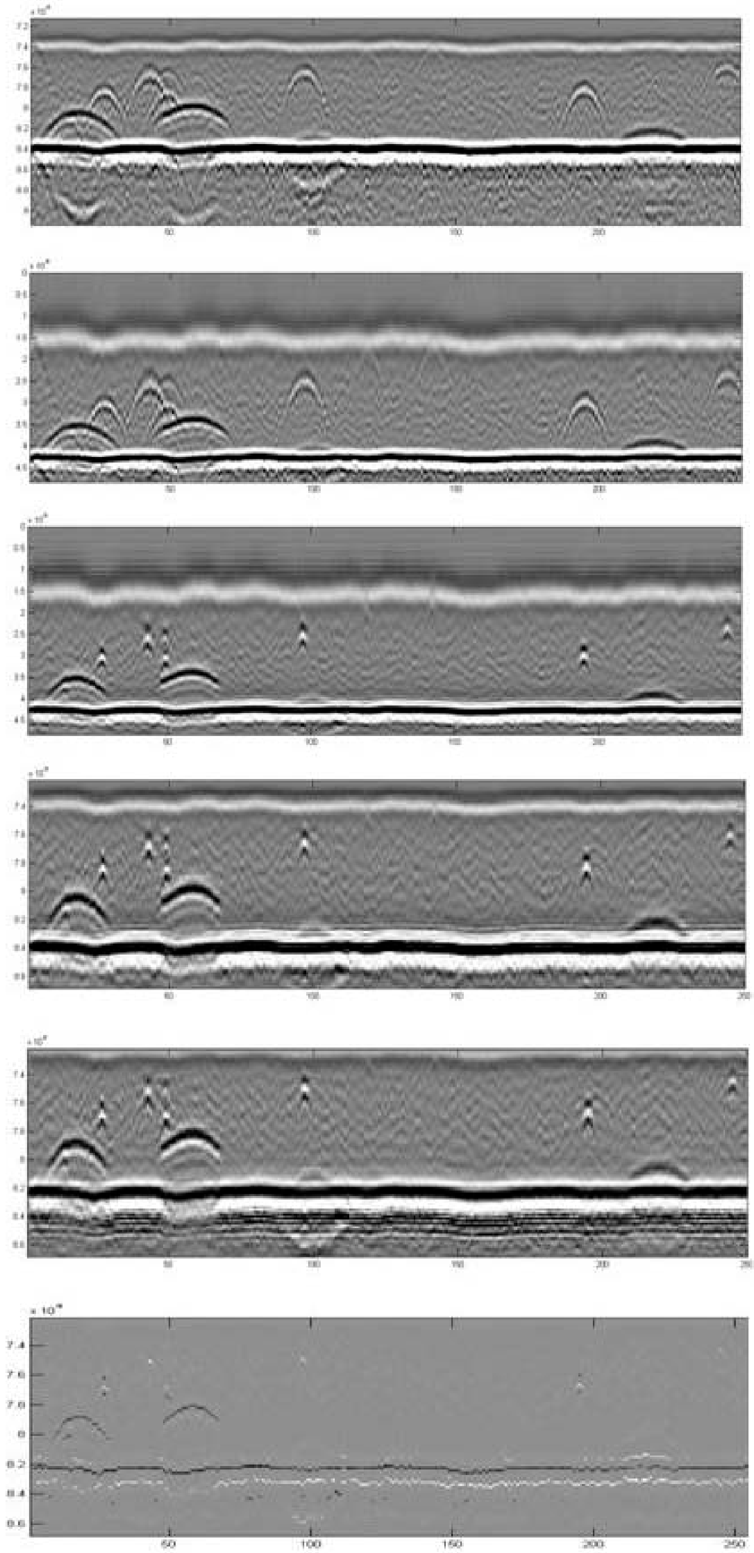


Fig. 13: Result of sparse-spike deconvolution

It is clear that the output is more easy to evaluate because disturbing influences (pulse length, hyperbolic shape, noise, interference) have been significantly reduced or even removed. optimization of the settings for SSD has to be carefully determined.

To enable a complete overview and comparison, all previous consecutive steps are shown in one figure, fig. 14.



Benchmark data set (input data)

After Normal Move-Out Correction

Imaged Zero-Offset data (IWEX)

True source receiver spacing restored

Zero phase image

After sparse spike deconvolution

Fig. 14: Summary of the results of all data processing steps

After processing, the data can be used for automated evaluation because of the mentioned improvements. Note that the polarity of the indications seems to be uniquely established.

APPLICATION TO ROOT CORROSION DATA

In fig. 3, it was shown how the remaining wall thickness profile of a weld with root corrosion could be calculated automatically using image processing. Only the ToFD image (as a bitmap) was used as a basis for this calculation.

Now, having demonstrated how data processing rather than image processing can be used to remove inherent features from the ToFD data, we will apply this to a root corrosion example similar to the one used in fig. 3.

The top image of fig. 15 shows the original data set as a result of the weld scan. In the middle image, the data has been correlated. Next, all data processing steps previously described have been applied: normal move-out Correction, zero-offset (IWEX), restoration of true source receiver spacing, zero phasing and sparse spike deconvolution. The result is shown in the bottom image of fig. 15.

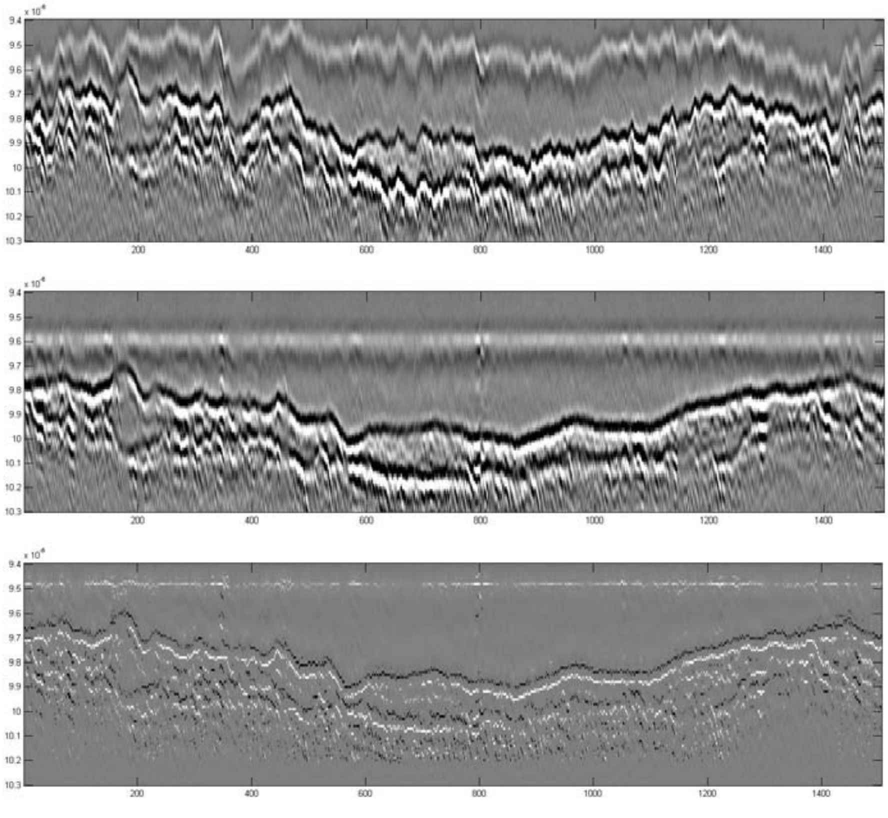


Fig. 15: Application of processing algorithms on root corrosion data

It can be seen that both the lateral wave and the profile of the back wall have been reduced to a thin line. This is a good illustration how the near-surface resolution and defect detection capabilities are improved by using these techniques. Possible small indications will have no influence on the final result. In addition, sizing result in ToFD data thus processed will be more accurate. Last but not least, interpretation will be more robust. The latter will make such processing algorithms especially fit to be used as a basis for automated interpretation of ToFD results.

DISCUSSION ON AUTOMATED EVALUATION

The interpretation of ToFD images is currently fully depending on the skills and attention of the operator performing the evaluation. When this evaluation can (partly) be replaced by software tools, this will enhance the speed and accuracy while the human factor (concentration) is reduced. Also the efficiency of reporting defect dimensions and position can be improved, although this is considered to be out of the scope of this development.

Several tools can be used for automated interpretation, like thresholds, defect recognition and tracking. The appropriate algorithms have to be developed or at least selected and optimized. Some basic tools are available in the current operational software, but most of this is done according to the operator skills.

The quality of each tool will depend on the Probability Of Detection (POD) with regard to the False Call Rate (FCR), similar to NDT in general. The settings of each tool must be optimized for maximum POD with an acceptable FCR. Mind that the optimum settings can differ between defect types and for different situations, therefore the use of a single 'optimum' set is arguable.

The development for automatic interpretation of ToFD images within Applus RTD is done in different phases. In the first phase, only looking at the ToFD image, we started off with a situation which is not too complex (root corrosion / erosion, where local minimum wall thickness must be measured). This approach will also be followed in further development of signal processing (phase 2), intended for the more complex jobs. Most of the developments for data processing have already been completed. Further steps will include optimization of the parameters to be used for each processing step, in order to finally arrive at an integrated processing algorithm that allows for reliable automated interpretation of weld inspection results, with maximum POD and minimum FCR.

Data processing and automated evaluation software is intended to be integrated, after completion of the development, into the existing Applus RTD ToFD software.

CONCLUSIONS

- Automated interpretation of ToFD images, based on the image itself as a bitmap, is possible on simple jobs where an unambiguous lateral wave and backwall signal are available, without noticeable indications of (weld) imperfections in between.

- Discrete processing steps on ToFD data can be used to remove inherent features from the ToFD data such as noise, signal shape, phase and beam spread, leaving only features related to the relevant indications that will have to be detected and make interpretation more straight-forward. These processing steps are normal move-out correction, zero-offset (IWEX), restoration of true source receiver spacing, zero phasing and sparse spike deconvolution.

- To arrive at a situation where ToFD data thus processed can directly be used for reliable automated interpretation; further optimization of all relevant processing parameters will be required.

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