Virtual flaws for NDE training and qualification

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Abstract
A typical qualification mock-up contains limited number of realistic flaws due to time and cost limitations. Increasing automated inspections offer new possibilities to overcome these limitations. In automated inspections, the data gathering and analysis phases are separated. This allows the introduction of flaw signal into the data, that were not present in the original data. On the other hand, the representativeness of these "virtual flaws" need to be confirmed. This paper introduces newly developed technique that allows introduction of realistic virtual flaws to data-sets of automated ultrasonic inspection data. The sample is first scanned before flaw introduction to establish baseline signal. Then, flaws are manufacture to the sample, and it is re-scanned. The difference in the datasets reveals the crack signal, which can be extracted. After the crack signal is separated, the it can be re-applied to an another location or locations. The new virtual crack data differs from the actual crack data, as the separated crack signal is superimposed to the (possibly different) background noise. At the same time, the signal is still realistic, since it is acquired from realistic crack and transferred unaltered. The data manipulation is undetectable from the manipulated.

Keywords: Ultrasonic Testing (UT), personnel training and certification, Qualification

1. Introduction

One long standing issue in NDE training and qualification is the availability and cost of relevant flawed test blocks. The test blocks and, in particular, the defects they contain should be representative to the actual inspection challenges that the inspectors are likely to encounter during field operation. However, manufacturing realistic test blocks and flaws is time consuming and costly. Consequently, the number and quality of test blocks is often limited. In training, where the required number of test blocks is high this leads to reduced representativeness of both samples and flaws they contain. In particular, EDM notches are often used instead of real cracks.

In qualification, the use of representative samples and flaws is considered indispensable. Consequently, the number of flaws is small to limit the overall cost of test blocks. This is becoming increasingly problematic now that there's more demand to get quantitative performance data from qualification. This, in turn, necessitates statistically significant number of cracks and trials. Also, as the number of qualified inspectors and re-qualifications increase, growing number of data-sets are needed.

Over the years, there has been number of approaches to overcome this. For training, there has been systems that mimic or manipulate the operation of standard inspection machine and introduce "virtual flaws" into the machine screen during operation [1]. However, these have not found widespread use, possibly due to complexity and cost of such systems.

Traditionally, the data gathering and analysis is done simultaneously and the operator can move the inspection probe arbitrarily to study a possible indication. The operator can also change probes to get more information regarding the source of the indication. All this has made it rather difficult to simulate actual inspection conditions with virtual instruments and flaws. However, in recent years, there has been a growing trend in use of automated inspections. Simultaneously, the use of multi-channel systems (phased array ultrasonic inspection or eddy current array probes) has dramatically increased the amount of information obtained from a single scan. The automated inspections greatly improve the reproducibility of the inspection and allow later re-analysis of the data.

With automated inspection, the data gathering and analysis are separated to distinct steps. The gathered data can be analysed in its entirety and possible indications can be compared to other areas in the data. Also, number of post-processing and data merging options are available for the operator to improve detection and characterization of indications. This separation also allows new possibilities for training and qualification. Since the analysis now operates, essentially, on pre-recorded data the need for different physical training samples and training data-sets are also separated. The data gathering can be trained and qualified on physical samples while the more demanding data analysis can be completed on separate (possibly unrelated) data set. The needs for the two steps are quite different. For the data gathering, representative sample is needed, but the costly need for high number of representative flaws primarily concerns data analysis. Consequently, being able to modify the gathered data-sets to include non-existing virtual flaws offer several significant advantages: the number of physical test blocks and flaws could be reduced, the number of flaws in the data could be increased to give statistically significant results and the number of different data-sets available could be increased so that every trainee or qualification candidate receives a fresh data set.

Simulation is nowadays routinely used as part of training and qualification. In qualification, its important use is in technical justification, where calculations can show the applicability and possible limitations of the chosen inspection procedure. Simulations could also be used, to provide data-sets for performance evaluation [2,3]. Recently Wirdelius & Persson [2] used simulation to provide virtual test data and also used detection criteria specified in the procedure to produce a full simulated POD curve. The challenge for using simulation for performance demonstration is, of course, proper validation of the simulation to make sure that the performance demonstrated on validation cases is descriptive of the actual inspection.

Another possibility to provide flawed data-sets is to manipulate existing, actually acquired data-set to introduce new flaws to the data. The flaws themselves can be actually acquired as part of some other data and can be introduced to numerous locations in the target data-set. This approach retains most of the advantages of the simulation approach, but since both the flawless data-set and the flaw signals are really acquired data from actual realistic flaws, there is better inherent representativeness to actual data. This is the approach taken in this paper.

As discussed above, the idea of using virtual data to train and qualify NDT procedures is by no means new. However, the present approach offers some advantages over the previously used ones, namely the better representativeness to the actual data. Recently EPRI [4] has done similar work, but there is no more detailed description available on the open literature. Furthermore, the approach described here has some unique features of its own.

The main challenge for this kind of approach is to make sure, that the manipulation done to the data files does not introduce any distinct features or artefacts that would affect the analysis of the inspector. Firstly, the flaw indication should be copied entirely, and no part of the flaw data should be left out. Secondly, only the flaw data should be copied - variations in noise etc. should not be copied together with the flaw. Finally, the embedding of the flaw signal to the acquired data should not introduce any new features such as abrupt changes in signal strength etc. that would indicate artificial changes.

2. Virtual flaws for NDE training and qualification

The approach taken here is then to: scan the sample in unflawed condition, introduce required flaws to the sample using standard Trueflaw technology, re-scan the sample in flawed condition, extract the flawed signal from the two data-sets and re-introduce the flaw signal(s) to the unflawed data to various locations to produce any number of flawed data sets. The principle is illustrated in Figure 1.

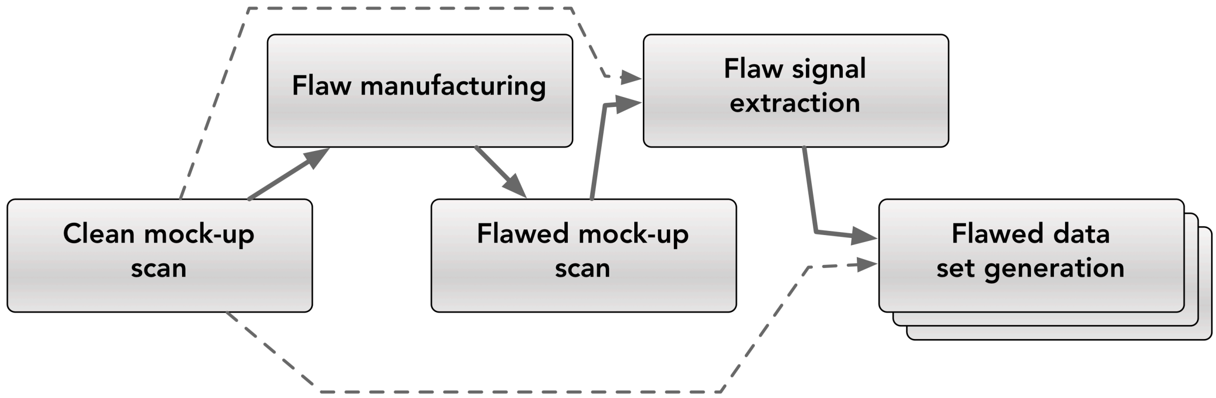

Figure 1. Principle of virtual flaw extraction and flawed data set generation

Since the only physical difference between the unflawed mock-up scan and the flawed mock-up scan is the introduction of the flaws, the flawed signal can be extracted, in principle, by taking the difference between the data files. In practice, there's random noise that will cause some additional difference to be registered. Consequently, the extraction is limited to areas around locations where the signal is above noise threshold. The process is not very sensitive to the cut-off point (as long as the whole flaw signal is included). The difference between two similar random noise signals is similar in character to the noise itself and thus does not introduce visible artifacts to the data.

In addition, there may be slight changes in the sample location between the two scans, which will cause differences in the signal. Thus, it may be necessary to introduce small adjustments to the data location to allow for optimal extraction.

After successful data extraction, the flaw signal can be superposed to the clean mock-up to various locations. Since the flaw signal is not altered or modified (just translated), the signal is still representative of the actual flaw signal.

3. Materials and methods

To test the process in practice, a pilot study was completed for small scale sample. The sample chosen was a simple stainless steel plate sample with weld in the middle. The sample was scanned with qualified procedure in clean condition. The procedure has been qualified by the Finnish qualification body (Inspecta Sertifiointi Oy). Then, a flaw was produced to the fusion line of the crack and the sample was re-scanned with the same procedure. Figure 2. shows the sample and scanning set-up. The scanning was done by Ville Lehtinen, DEKRA Industrial Oy. Examination was carried out using qualified phased array ultrasonic technique based on Zetec's PDI qualification. Used instrument was Omniscan PA (32/128), Manual Pipe Scanner and Zetec PDI transducers (TRS-technique). The probes used were 1.5 MHz matrix probes (3 x 5 elements in each probe). The sample was scanned with three scan lines.

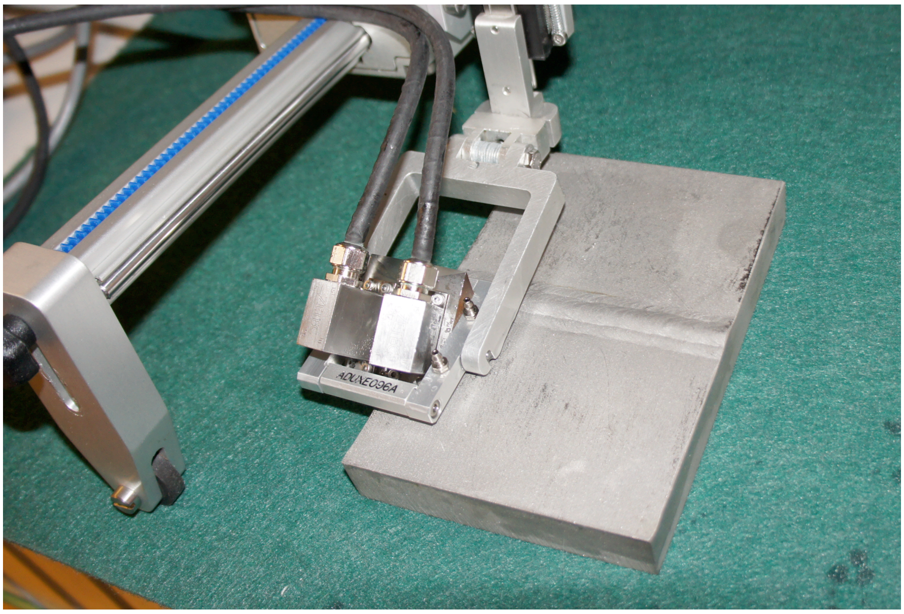
Figure 2. Sample and scanning set-up.

After scanning, the flaw signal was extracted as described in section 2 and re-introduced to the clean data set with 20 mm offset. The small size of the sample did not allow for multiple flaws to be introduced, so in this pilot study, only one flaw was superimposed to the flawless data set.

4. Results and discussion

The resulting data file was compared with the flawless and flawed data sets. The data sets were given to several inspectors with request to try and find possible problems or artifacts in the modified data. The data compared favorably and no artifacts were reported in the modified data. Figures 3 - 5 show the raw (un-merged) data in various ways. Figure 6 shows a sample A-scan from the image. Initially, there was a concern, that although the modifications are indistinguishable from the sectional typical analysis images, it might be possible to notice difference if the inspector went down to analyze the individual A-scan images. However, in analyzing several A-scan images, no problems were seen and the modified signal integrated well with the A-scan images in all cases.

Figures 7 and 8 show the merged images. It can be seen, that the merge images are produced from the modified data as expected and no trace of the modification can be seen. This is to be expected, since all the raw data images showed good results and since the merge process has a smoothing effect on the data and thus is somewhat forgiving to small problems in the data. This smoothing effect improves the inspection by reducing the effect of natural problems occurring during the normal scanning of the data, but it also affects favorably possible artificial problems from data manipulation.

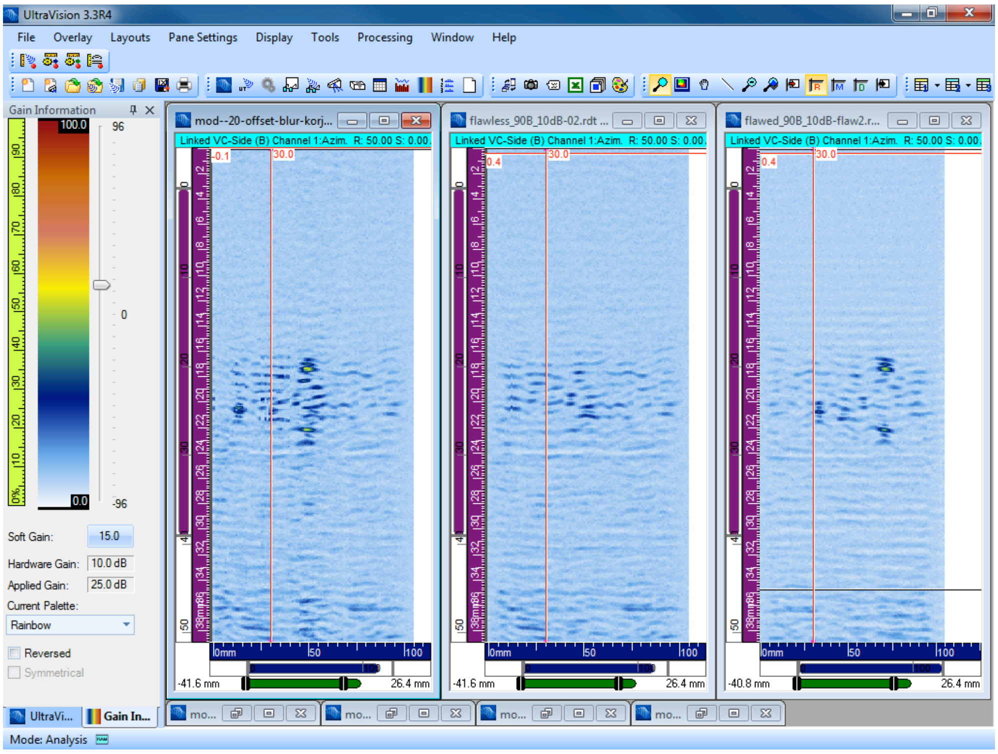

Figure 3. The three data-sets compared; from left to right: the modified data, flawless data and flawed data. The flaw signal has been moved in the modified data. Also, the flaw signal is superimposed to the local noise and thus looks a bit different from the original flaw signal (as it should).

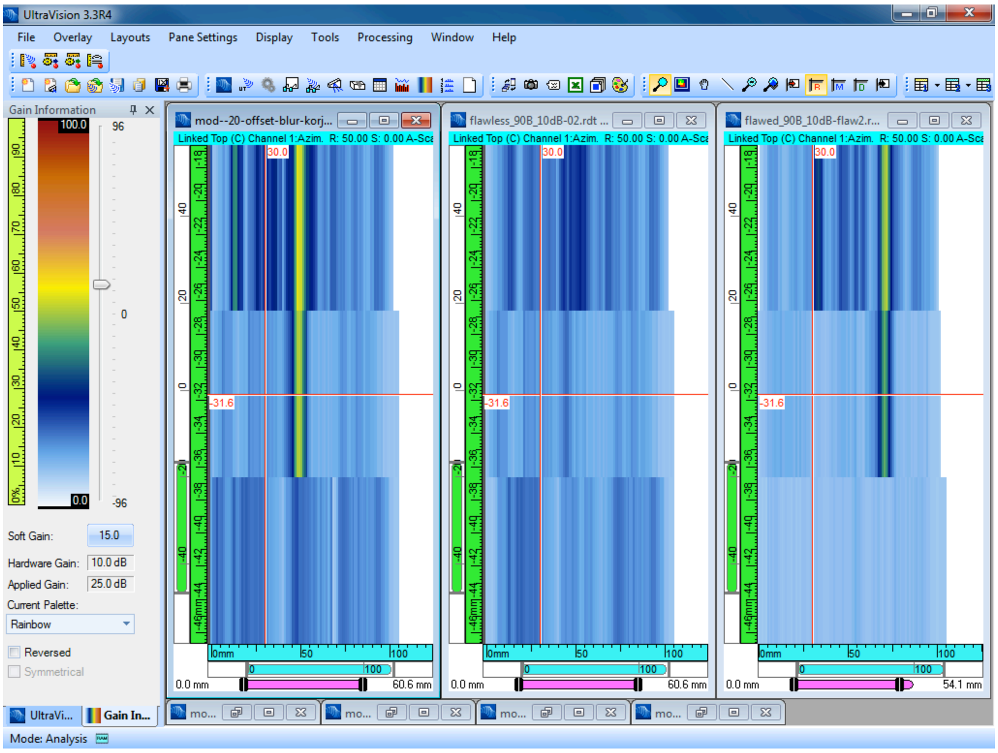

Figure 4. C-scan showing that the flaw signal has been moved in all the scan lines.

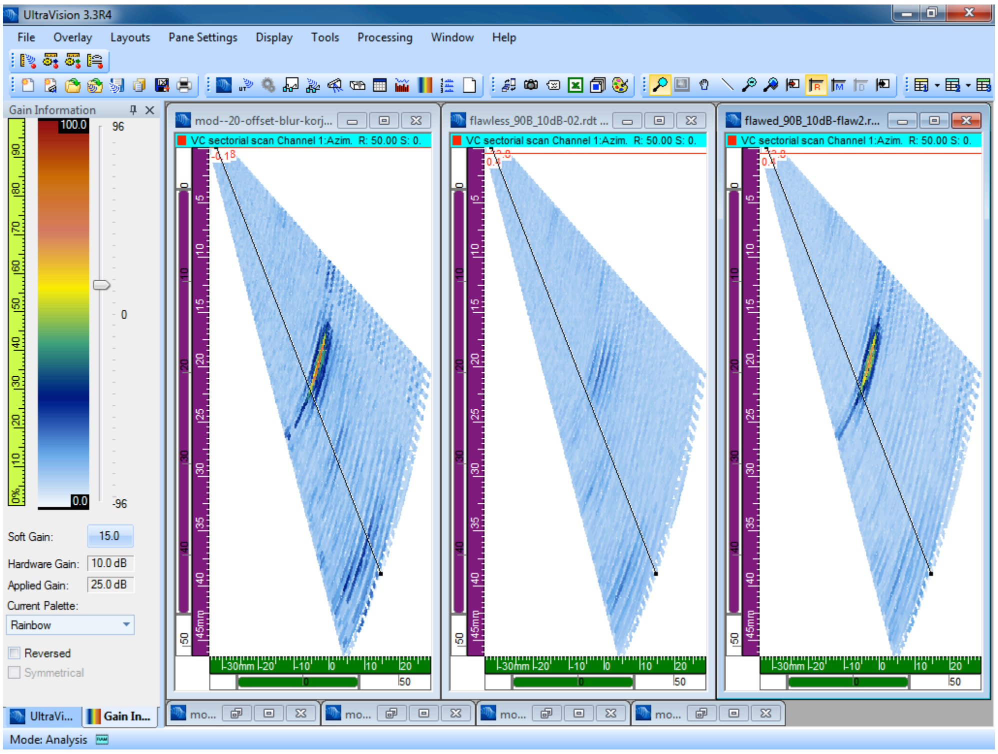

Figure 5. Sectional scan showing that the flaw signal has been successfully modified in all sample angles.

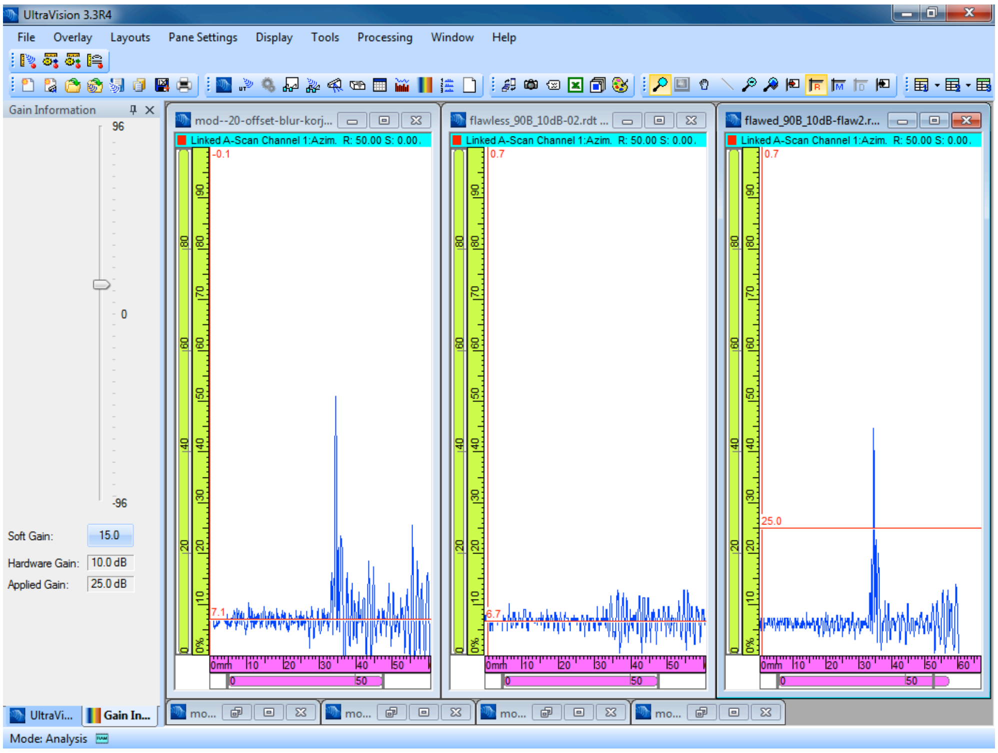

Figure 6. Sample A-scans showing how the extracted flaw signal superimposes nicely to the level of individual A-scans, even when the noise level of the unflawed sample at the specified location is different from the original location.

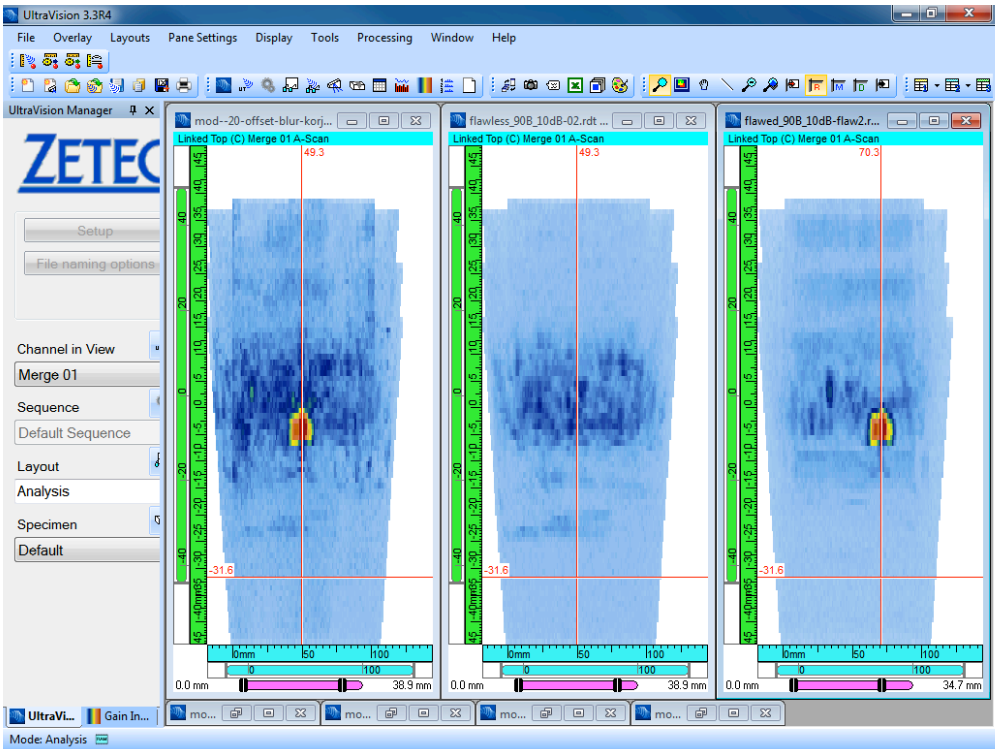

Figure 7. Merged data set from the top showing that the modified data file produces the expected merge images as well.

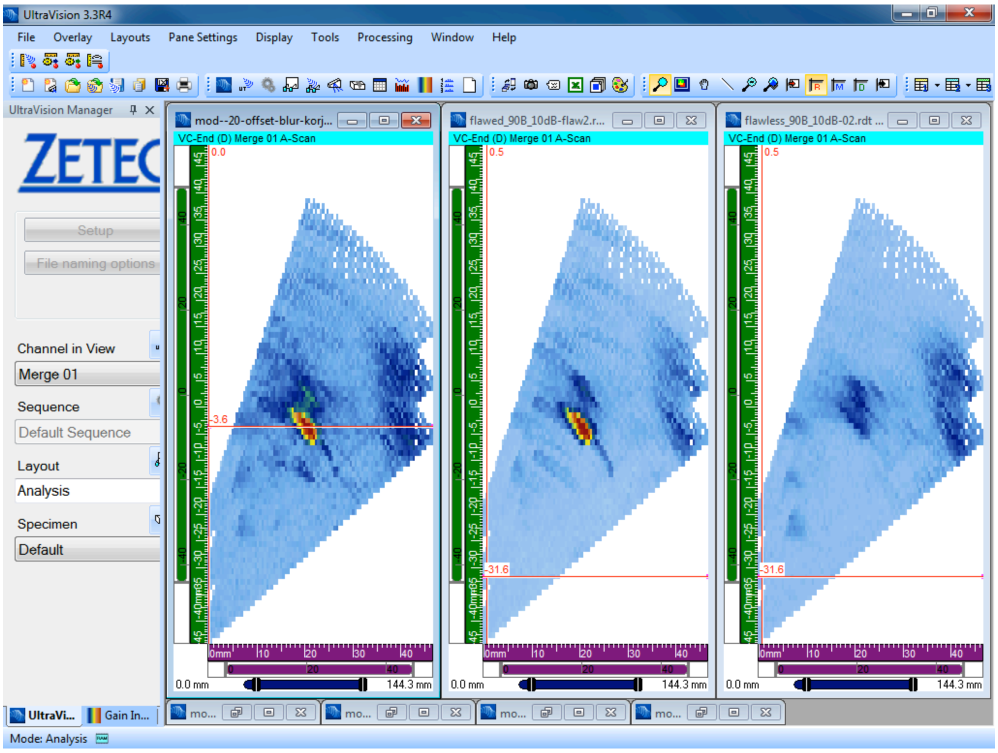

Figure 8. Merge data from sector scan showing that the the modified data file produces expected merge images and that the flaw signal integrates well to local noise.

4. Conclusions

The pilot project showed, that the data manipulation and introduction of virtual flaws is an effective technology that can now be used to simultaneously reduce cost and improve the statistical quality of qualification. It also offers interesting opportunities for training of data analysis. Furthermore, the technology could be used in ways described in Burkhardt et al. [1] as more integral part of NDT quality improvement.

Acknowledgements

The modified data sets were reviewed and commented on by several finnish NDT experts, whose support is gratefully acknowledged: Ville Lehtinen (DEKRA Industrial Oy), Jonne Haapalainen (VTT), Esa Leskelä (VTT) and Ari Koskinen (VTT).

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