TITLE: ULTRASONIC TESTING OF AVIATION MATERIALS WITH 2D ARRAYS APPLYING DDF IN TRANSMISSION AND RECEPTION

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RESUME

This report introduces a new concept for the investigation of highly damping titanium billets avoiding complex multi-transducer solutions as well as highly sophisticated image processing algorithms. Instead, we present an approach using a single 2D phased array probe. With the probe parametrization capabilities of the high definition industrial ultrasound evaluation electronics USIP|xx at hand, we apply post-acquisition processing in order to resemble DDF targeting for zones of different depths. The resulting setup significantly reduces the inspection time and is suitable to test for small inclusions from near-surface down to material thickness beyond 180mm.

1 – INTRODUCTION

Highly stressed components, in particular for applications in aviation, require sensitive inspection in order to avoid smallest inclusions within the material. This is generally carried out by full body scans applying focused transducers at high frequencies. While this is easily possible for fine grained materials, like forged steels, it may be an issue for other materials, e.g. titanium or Ni-based alloys, which become more and more popular. Inspection of these materials requires the use of several transducers to cover the entire testing range, which multiplies the inspection efforts and therefore reduces productivity.

Several years ago, GE introduced the LOGIQ 9 system which makes use of a 1.5D-array, capable to include a 4 zone transmit DDF. Complex software algorithms combine the individual images, thereby emulating a cross-sectional view of the material at extremely high resolution. With this system at hand the inspection can in principle be performed in a single scan. The shape of the transducer however limits its application to testing of planar specimen or finite size. Differently shaped phased array transducers are required for testing of areas...
with fixed curvature like, e.g. radii. As a result, all these arrays are designed to the particular inspection task and do not have the flexibility to perform full contour scanning.

### 2 – RESULTS

In this study we apply a broadband 2D array with a center frequency of 10MHz and a pitch of 1.0 x 1.0mm, as shown in Figure 1. The probe is driven by the newest generation USIP|xx electronics, equipped with four PA64 modules hosting in total 256 individual pulser channels to fire each element individually. The symmetric arrangement of the transducer elements allows for beam steering and focusing in both x and y directions, which will give us the flexibility to adjust to the ultrasonic beam to a variety of contours.

<table>
<thead>
<tr>
<th>Number of Elements (x x y)</th>
<th>16 x 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element Pitch (x x y) / mm</td>
<td>1.0 x 1.0</td>
</tr>
<tr>
<td>Center Frequency / MHz</td>
<td>10</td>
</tr>
<tr>
<td>Relative Bandwidth</td>
<td>~70%</td>
</tr>
</tbody>
</table>

**Figure 1: Probe parameters and geometry**

The electronics has a dynamic range over 95dB and a maximum pulser voltage of 200V per channel. Using a full 16 x 16 elements aperture we are therefore capable of inspecting even high material thicknesses and highly damping material.

An example is given in Figure 2 showing measurements under normal incidence on sample titanium billets with a total material thickness of up to 185mm. The water path was set to a fixed value of 50mm while scanning was carried out applying a pulsing sequence of eight individual shots with calculated focal depth in material of 2.5mm, 5mm, 10mm, 20mm, 40mm, 80mm, 160mm, and 320mm.

The horizontal axis denotes the sound path in the target material with the water/metal interface I to be seen on the left-hand side of each A-Scan data and the backwall B on the right-hand side, respectively. In all images, the blue gate indicates the reflection of a flat bottom hole (FBH, F) with a diameter of 0.8mm. The reflector depth ranges from (a) 3.2mm to (d) 114.3mm.

**Figure 3** gives the resulting distance-amplitude-correction (DAC) curve derived from the experimental raw data. Data labels indicate the focal point distance with the highest reflector amplitude. As can be seen in the diagram the material requires amplification of about 50dB across the tested volume. Note that the electronics can apply individual filter settings to each evaluation channel so we can to reduce high-frequency noise towards high material depth and therefore increase the signal-to-noise ratio to above 15dB, i.e. sufficient for automated testing.
The figures above demonstrate that the system is capable of detecting smallest inclusions in the entire range from near-surface region down to high material thickness. With this we are able to cover the entire testing range with a single scan.
However, sequential pulsing requires several acquisition cycles which are time consuming. We are able to follow a more efficient and even faster scan plan by making use of the Paintbrush principle: In this approach we break with the conventional transmitter/receiver relation common to standard industrial solutions. Instead we apply a single transmitting cycle and store the fully digitized A-Scan data of each channel in the memory. In a second step, data can be retrieved from the memory for evaluation in almost any configuration. Within these virtual probes, the user is able to apply custom delay laws to the original data. Moreover, this second step can be repeated several times with completely different receiver combinations and delay laws.

A possible scenario for this tool is to compensate for misalignment between the transmitter ultrasonic beam and the actual reflector orientation. That flexibility will lead to significantly higher amplitudes, thus increase the probability of detection [1]. In our case, we employ multiple data re-evaluation to generate several virtual probes sensitive to different material depths. That is, we create a multi-zone DDF by a single acquisition, as illustrated in the simulation data of Figure 4.

Another important aspect of the USIP|xx electronics is the possibility to evaluate multiple virtual probes in parallel. Flexible software algorithms allow for parallel processing of up to eight virtual probes per 64 elements, significantly increasing throughput. Given the probe configuration applied in this study, scanning is four times faster than with the sequential pulsing as shown in Figure 5.

The experimental realization of this procedure is given in Figure 6, showing data to the corresponding measurements of Figure 2.
Figure 5: (a) Sequential pulsing as shown in Figure 2 requires eight acquisition steps following the conventional transmitter/receiver principle. (b) Paintbrush acquisition applies a single (unfocussed) transmitting cycle followed by multiple re-evaluations of the recorded data in virtual probes with different focal depths (indicated by numbers). Parallel processing will reduce the inspection time by a factor of four. (c) Paintbrush using multiple transmitting cycles for an improved coverage of the testing area.

reflector sound path in material  
(a) 3.2mm, (b) 12.7mm, (c) 50.8mm, (d) 114.3mm

focal depth in material  
(a) 5mm, (b) 20mm, (c) 40mm, (d) 160mm

Hamming filter settings  
(a) 4 – 15MHz, (b) 4 – 15MHz, (c) 4 – 7MHz, (d) 4 – 7MHz

digital gain  
(a) 14dB, (b) 24dB, (c) 29dB, (d) 42dB

Figure 6: Paintbrush acquisition of FBH 0.8mm at different depths in titanium samples.
As evident from the data, the paintbrush acquisition in normal incidence results in a pronounced interface and backwall echo, when compared to focused transmitters. Another observation drawn from the experimental data is the need for additional gain of about 14dB in the near-surface region, whereas there is no loss at larger sound paths. The full DAC curve derived from the data is depicted in Figure 7.

![Figure 7: Recorded DAC curve for both sequential pulsing (red) and the paintbrush acquisition (blue). Data labels indicate focal point distance with the highest reflector amplitude.](image)

Both effects can easily be explained by the sound field characteristics of the unfocussed transmitter, in particular its relatively low intensity in the near-surface region, cf. Figure 4. It is reasonable to assume that an additional transmitting cycle focused to the near-surface region will improve the sensitivity below 50mm. In fact, we can introduce this cycle without extending the overall inspection time, as indicated in Figure 5c. Yet, with the given setup all reflectors could be detected with a signal-to-noise ratio above 18dB.

### 3 – CONCLUSION

Ultrasonic testing of highly stressed or highly damping material is very time-demanding. With conventional setups, typically multiple scans with different transducers are required to cover the testing range, followed by complex data processing. Using a 2D matrix phased array probe in combination with the USIP|xx electronics supplied by GE allows to combine these inspection tasks in a zonal DDF approach, able to cover the entire dimension range in a single scan.

The paintbrush approach, including multiple parallel evaluation channels, will give full flexibility to the operator and will increase the productivity significantly, while keeping the ability to detect smallest inclusions with a signal-to-noise ratio ranging from 15dB to larger than 20dB.

### REFERENCES