By pulsing an acoustic emission (AE) sensor, AE of reproducible energy is artificially generated and used for the sensor coupling test. AE waves may travel from any AE source to a receiving AE sensor over multiple wave paths, e.g. over the shell or the liquid content of a pressure vessel. Waveform data may reveal different wave arrivals by so-called sub-events. Each wave arrival appears in waveform data by sub-events of different properties like arrival time, amplitude, frequency spectrum and appearance of its envelope. Intelligent data processing software could automatically consider different wave propagation paths of an individual test object. This may answer questions like “did the wave of an individual sub-event propagate over the shell or over the liquid content of a pressure vessel?” and consider the right travel path and wave velocity for location calculation. By this, AE testing results could become in general more reliable. This paper describes some basic work towards that objective. Development of such software would need feedback of waveform data from the sensor coupling check from real test objects.

Keywords: Acousto-Ultrasonics, pulsed-AE, AE-wave-paths.

1. Basics of the software controlled sensor coupling test

The original purpose of the software controlled sensor coupling test was to offer the possibility that any channel can be selected by software to emit stimulated AE into a test object and to receive the resulting AE wave at the position of neighbouring sensors. Each receiving sensor converts the wave to an electrical AE signal which is converted to digital AE data by an AE signal processor as usual.

![Figure 1. Block diagram of the “pulse-through” mechanism for the software controlled sensor coupling test.](image-url)
1.1 Pulse-through principle
In a so-called “pulsing sequence”, one channel is set to pulsing mode. That means, a few electrical pulses from a central pulse generator are passed through the channel up to the piezoelectric element. This causes one artificial AE event per pulse. Then the next channel is selected for pulsing until the last channel completes the pulsing sequence.

In “pulse-through mode” a programmable pulse amplitude in range 1 V to 450 V_{PP} can be used. The high amplitude maximum allows to receive pulses even over a very attenuating wave propagating path, e.g. through a polymer layered riser tube. In pulsing mode, the preamplifier is switched off and the pulse is passed through up to the piezoelectric element over relay contacts. Each pulse is also fed into the signal processor in order to generate a hit data set with accurate time of the pulse. All data shown in this paper are created by the pulsethrough principle. Chapters 1.2 and 1.3 are included for completeness only.

1.2 Auto sensor test in self test mode
This mode is defined by [1]: An electrical pulse is generated inside of a preamplifier in response to a control pulse on the 28 V power/signal line from the signal processor. The pulse is passed on to the piezoelectric element. The pulse amplitude can be modified in a small range by modifying the width of the control pulse. The preamplifier stays in operation and is driven into saturation by the pulse. After some settling time the preamplifier becomes able to receive an acoustic response from the test object. Under favorable circumstances, a change of coupling quality can be evaluated from the response on the emitted AE wave.

1.3 Auto sensor test in near neighbor mode
This mode is defined by [2]. A pulsing sequence is generated similar to the pulse-through principle described in 1.1 above, but the pulse is generated inside the preamplifier as with self test mode described in 1.2. The pulse drives the preamplifier of the pulsing channel into saturation.

1.4 Pulsing table
The amplitudes received during a pulsing sequence are shown in a pulsing table, see example of a 6-channel configuration in Figure 2. Lines are headed by the pulsing channel number, columns by receiving channel numbers. Each cell shows the average of the few amplitudes (pulses) measured by a receiving channel. Non-plausible sensor responses can easily be identified. One of multiple pulsing sequences can be addressed by its tab on top of the table.

![Figure 2. Pulsing table for a 6-channel configuration. Channel 1 received 82 dB_{AE} from pulsing channel 4](image-url)
In addition, a variant of the pulsing table shows differences in amplitudes of two pulsing sequences, e.g. one before and one after a test. This variant helps to quickly see whether acoustic coupling was constant before and after a test or has changed between any sensor pair.

2. Further usage of stimulated pulsing data

Stimulated AE data from pulsing sequences can be analysed and graphically and numerically presented like normal AE data, e.g. for checking location calculation, clustering, attenuation profiles and more.

Data from pulsing can be separated from normal AE data by a filter condition: “PULS > 0”. The “PULS” flag is selectable from the “Parametric results” dialog. The PULS Flag is set to 1 before the first channel is set to pulsing mode and back to zero after the last channel is set from pulsing mode to normal mode.
3. Advanced usage of the software controlled sensor coupling test

After looking at sensor coupling test data obtained from a few test objects, we discovered potential for an advanced, beneficial usage of those kind of data.

The software controlled sensor coupling test always generates AE at a well defined position, namely the position of the pulsing sensor and at an accurate source time, which is measured as arrival time by the pulsing channel. From the position of each sensor, the distances of different propagation paths between each pair of sensors can be calculated. With a cylindric structure, most important propagation paths are the shortest and the next longer distance over the surface of the test object, and the shortest distance over the pressurization fluid in the test object. See the three paths from S1 to S2 in Figure 5.

3.1 Example 1: Thin walled water-filled cylinder

Outer diameter of cylinder: 125 cm, height of cylinder (without end caps): 120 cm, wall thickness of cylinder: 0.63 cm.

A program has been written to calculate the three distances (see Figure 5) between any two positions on a cylinder and the resulting arrival times using a defined velocity of sound for each path. The following abbreviations were used for the entered velocities, distances and arrival times, the numbers are results for one example of positions S1 and S2:

Entered velocities and positions S1(X1, Y1) and S2(X2, Y2):

- `svel` = 0.50 cm/µs  s0-velocity
- `avel` = 0.32 cm/µs  a0-velocity
- `waterv` = 0.15 cm/µs  water velocity
- `X1` = 148 cm  circumferential pos. of the source (range -196.35 … +196.35)
- `Y1` = -25 cm  height position of source (vertical cylinder)
- `X2` = -130 cm  circumferential position of sensor 8
- `Y2` = -130 cm  height position of sensor 8

Calculated distances:

- `Degree` = 105.15°  angle between S1 and S2 (for water distance calculation)
- `surfDists` = 115 cm  shortest surface distance
- `surfDistl` = 278 cm  longer surface distance
- `volDist` = 99.6 cm  water-path distance
Calculated arrival times:

\[
\begin{align*}
s_0\text{\_short} & = 230 \, \mu s \, \text{delta-t of source to s0 arrival, refers to T=0} \\
d_{a0\text{\_short}} & = 129 \, \mu s \, \text{short path a0-arrival from T=0} \\
d_{s0\text{\_long}} & = 326 \, \mu s \, \text{long path s0-arrival from T=0} \\
d_{a0\text{\_long}} & = 639 \, \mu s \, \text{long path a0-arrival from T=0} \\
d_{\text{water}} & = 434 \, \mu s \, \text{water path arrival from T=0}
\end{align*}
\]

3.2 Example 2: Thick walled water-filled cylinder

Dimensions:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No of channels used:</td>
<td>50</td>
</tr>
<tr>
<td>Length:</td>
<td>42.61 m</td>
</tr>
<tr>
<td>Diameter:</td>
<td>5.48 m,</td>
</tr>
<tr>
<td>Thickness (shell):</td>
<td>14.5 cm</td>
</tr>
<tr>
<td>Thickness (bottom head):</td>
<td>7 cm</td>
</tr>
</tbody>
</table>

We received only a part of the test data. Only stimulated data from sensors 1 to 4 are available in the received data, with only 2048 samples at 5 Megasamples per second (MSPS) record length and 200 samples pre-trigger, what gives a visible length of 40 µs pre-trigger and 370 µs post-trigger. See Figure 10.
Figure 8. Sensor positions at (unwrapped) cylindrical part of pressure vessel

Figure 9. Sensor positions at top head (left side) and bottom head (right side). 4 sensors belong to cylindrical part. Only the distances between channel 3 and 42, and between 2 and 43 are short enough to see the Rayleigh wave arrival in the length of the recorded waveform data in Figure 10.

Figure 10. AE stimulated by sensor 3 and recorded by sensor 42

Figure 10 shows a waveform picked up by sensor 42, emitted by pulse stimulated sensor 3. The large amplitude burst beginning at about 275 µs fits very well to the velocity of the Rayleigh wave.
Figure 11 shows same waveform as Figure 10 but zoomed around the time of the first threshold crossing (FTC) (also called arrival time). Obviously, first components of the wave arrived about 25 µs before the measured arrival time. That means at such a thick walled structure, the arrival time measurement bears some uncertainties. The question comes up, whether the peak time gives a more reliable time criterion for distance evaluation and location calculation than the arrival time.

The first 4 columns of the following table are taken from the listing of the channel 3 stimulated event. It shows:

<table>
<thead>
<tr>
<th>CHAN</th>
<th>Sensor number</th>
</tr>
</thead>
<tbody>
<tr>
<td>DT1X</td>
<td>the difference between the measured arrival time of each subsequently hit channel to that of the first-hit channel (here channel 3).</td>
</tr>
<tr>
<td>A</td>
<td>the highest amplitude (peak amplitude) detected during the hit in dB$_{AE}$.</td>
</tr>
<tr>
<td>R</td>
<td>the risetime, defined as time of A minus arrival time (FTC-time).</td>
</tr>
</tbody>
</table>

The next columns show following calculated results:

- **PkT** Peak time or time of A, the time at which the highest amplitude is measured, $= DT1X + R$
- **Dist_DT** Distance derived from arrival time, $= DT1X *$ arrival time velocity (AV, 5.58 m/ms)
- **Dist_PKT** Distance derived from peak time, $= PkT *$ peak time velocity (PV, 2.95 m/ms)
- **Percentage** The deviation of both distances in percent, $=((Dist\_DT/Dist\__PKT)-1) *100$
A positive percentage means that Dist_DT is larger than Dist_PKT. An example can be seen in Figure 11: Fast wave components are attenuated below threshold, so the measured arrival time, detected at the time of the first threshold crossing, reflects the later arrival of wave components of higher energy content. This explains the occurrence of a positive percentage at distances above 4.7 m.

A negative percentage means the peak time occurs later than calculated for the assumed peaktime-distance. This can be seen with channels 6 and 7. There the risetime is a bit larger than at channels 2 and 4. We could not look deeper into this phenomenon since the peak time is behind the recorded waveform length.

Since there are only very few occurrences of small negative deviations, we believe a peaktime derived delta-t will lead to better location results than the arrival time delta-t, if the wall thickness is large and the AE source is at the outer surface of the object.

4. Conclusion

With two examples, a thin walled and a thick walled test object, this paper shows that waveform data from the software-controlled sensor coupling test bear valuable information about details of wave propagation at the test object which might be helpful for the understanding of the involved wave propagation effects.

We would like to perform more studies on stimulated data from real test objects in order to define goals for the development of software that extracts most helpful information from such stimulated data. Substantial efforts are needed to equip a large structure with AE sensors for a properly performed AE test. It is very easy and needs no extra efforts to gather waveform data in addition to hit data during the automated sensor coupling test.

We herewith ask AE service providers to switch on waveform recording (TR-recording) during the automatic sensor coupling test, use several ms long waveform length, and about 1 ms pre-trigger setting, and pass-on to us such data for further analysis. We will treat such data confidentially and eliminate any hint to the testobject.

References

1 ASTM E2374-10 “Standard Guide for Acoustic Emission System Performance Verification,” Section 5.1.3.2. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshocken, PA 19428-2959, US, service@astm.org, www.astm.org

2 ASTM E2374-10 “Standard Guide for Acoustic Emission System Performance Verification,” Section 5.1.3.1. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshocken, PA 19428-2959, US, service@astm.org, www.astm.org