On the integrity investigation of pressure tanks through acoustic emission test

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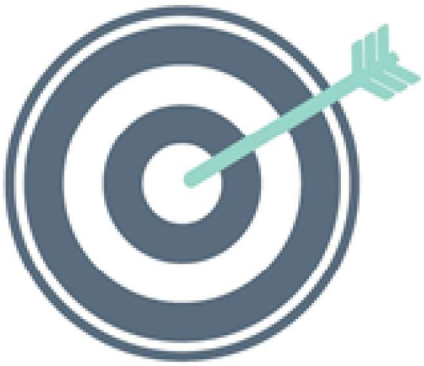
1st EPERC International Conference - Non-Destructive Examination - In Service Inspection and Operation
Rome, 2nd April 2019

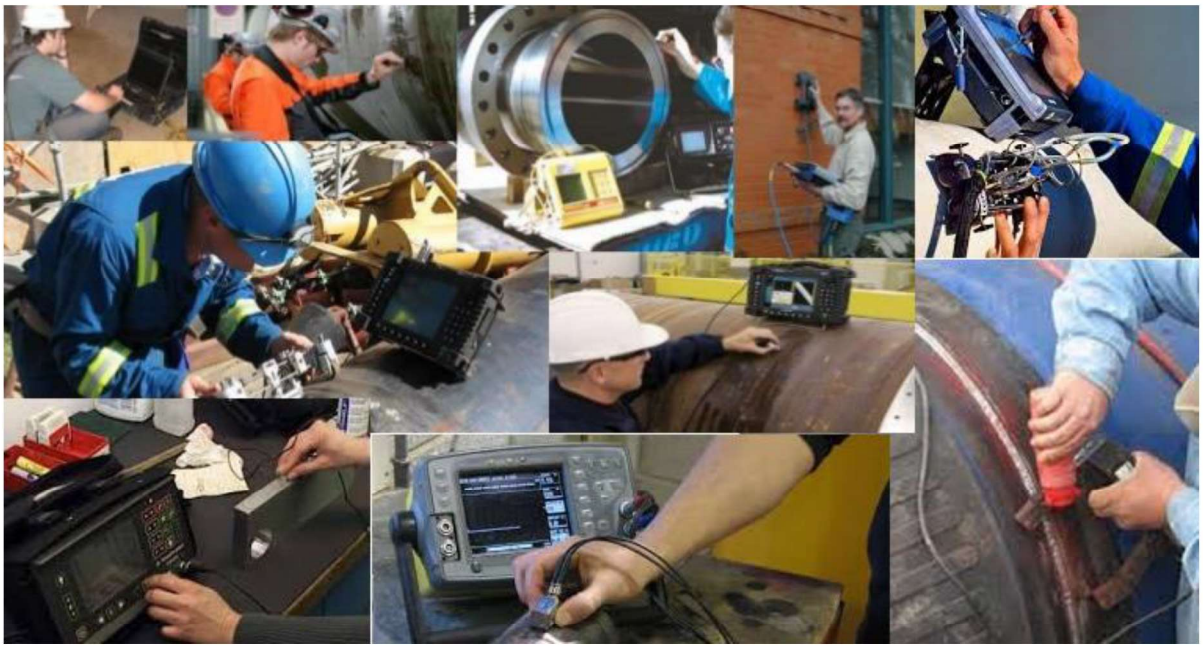
Aim



To verify the **structural integrity** of five 1000 l LGP **vertical tanks** with **artificial defects** by applying **acoustic emission test** according to the **ISPESL procedure**

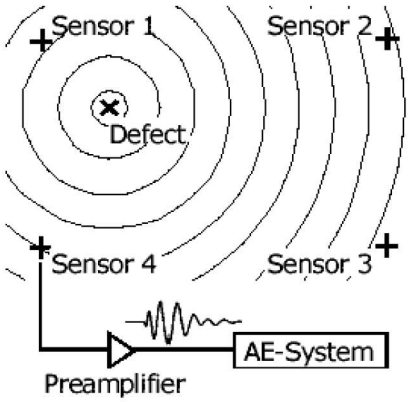
Non-destructive testing

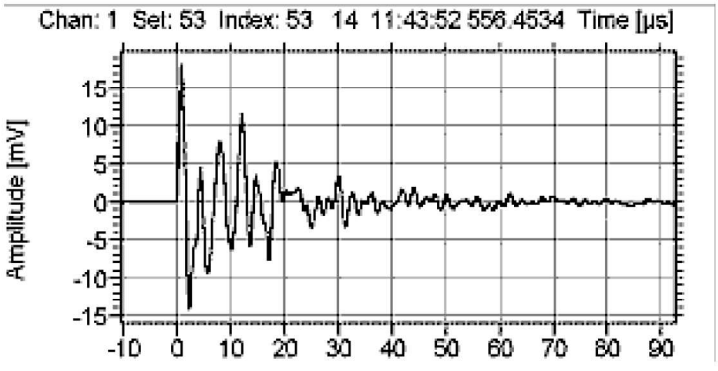
Nondestructive testing (NDT) is the process of inspecting, testing, or evaluating materials, components or assemblies for discontinuities, or differences in characteristics without destroying the serviceability of the part or system



Acoustic Emission (AE)

- AE tecnique allows detecting damages, cracks and weld defects
- Detection of dynamic defects that generate acoustic activity under external dynamic stress
- Transiet signals (burst) represent the studied signal for gathering useful information on structural integrity





AE tecnique– Pros and cons

- Passive tecnique (not requiring artificial acoustic excitation)
- Volumetric evaluation of the structure
- Not depending on the geometry
- Access only for sensor placement on the top without digging up the tanks

- Not detection of static defect
- High sensitivity to the background noise
- Low sensitivity to the geometry of the defects
- Irreversible test (Kaiser Effect)

Procedura ISPESL

ISPESL procedure accounts for the detection of acoustic activity due to a mechanical load imposed to tanks through its pressurization

Operating steps

- Choice of pressurization system
- Choice of measurement system
- Application of EA sensors
- Pressurization system connection to the tank
- Initial verification tests
- Recording of the background noise
- Tank pressurization
- Final verification tests
- Pressurization system disconnection

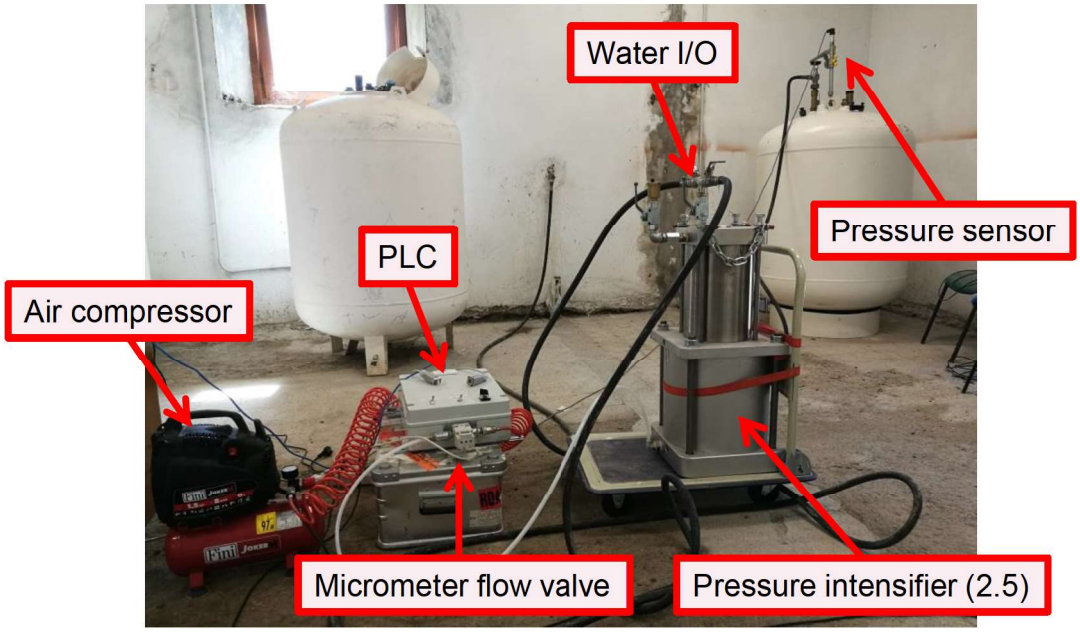
Experimental procedure

- Performed at Engineering Laboratory of University of Tuscia
- Performed by following the operating steps of the ISPESL procedure
- Examined five LGP underground vertical storage tanks (model *AMICO 1000 l)*
- Tested tanks presented artifical defects produced during the realization phase

Experimental setup consisted in:

- Pressure sensor for monitoring the pressure of the tank
- Four piezoelectric sensors as AE measurement system
- Vallen system for the signal processing
- Notebook for data acqusition and offline post-processing
- Hydraulic pressurization system to provide external stimulus

Pressurization system

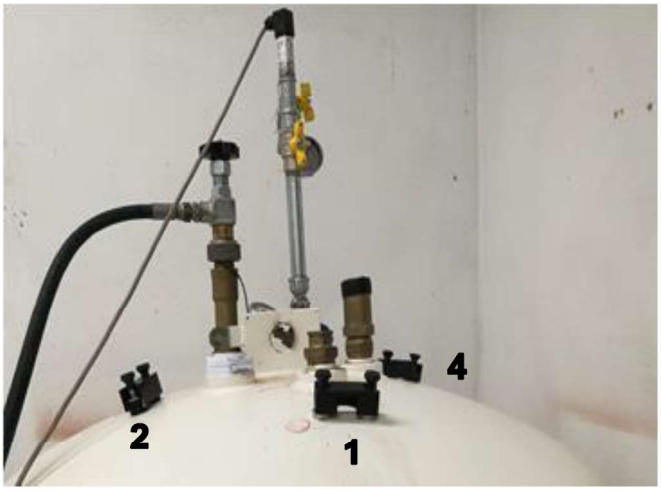


- Compressor sends air to the piston at 8 bar;
- Piston pushes water inside the tank through the pressure intensifier;
- PLC set the opening of the valve to guarantee the linear pressure gradient.

Experimental protocol (1)

AE sensor placement

- 4 Piezoelectric sensors
- Placement following the symmetry of the tank
- Two couples of sensors spaced about 500 ± 100 mm
- Fixed with magnetic brackets



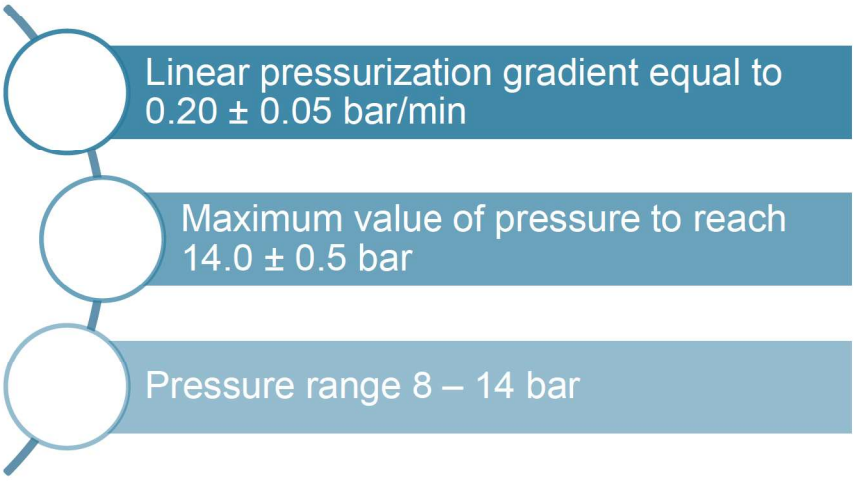
Testing three configurations:

- 4 sensors
- 2 sensors (1 e 3)
- 2 sensors (2 e 4)

Experimental protocol (2)

Pressurization stage

- After successful initial verification tests
- Only one pressurization for each tank (Kaiser effect)
- No interruptions during the stage
- Recording the AE events



Experimental protocol (3)

During the pressurization stage the following parameters were monitored in real time if the trial must be precautionary stopped

Indice	Limit
$\gamma_{max} > \gamma_{stop}$	0.9
A_{75}	25
A_{85}	8
A_{CORR}	1000

Data analysis (1)

Computation of the following indices for all the tested combinations

- **ICSE** – Synthetic qualitative index (global activity and how energy is distributed)

$$ICSE = f\left(HC, k, EC, \Delta p, AC\right)$$

- **ISRE** – Time history index (time evolution of energy release)

$$ISRE = g\left(\Delta EC, \Delta p_{ISRE}\right)$$

where:

- HC: Number of cumulated hits considering all the AE sensors;
- k: Number of most energetic events needed to account for 50% of EC;
- EC: Cumulated energy considering all the AE sensors;
- Δp: Pressure variation during the trial;
- AC: Area under the curve of EC as a function of HC;
- ΔEC: Cumulated energy in the specific pressure range Δp_{ISRE};
- Δp_{ISRE}: Pressure range of 0.8 bar;

Hit
Duration > 30 μs
Amplitude > 40 dB
Distance > 2 ms

Data analysis (2)

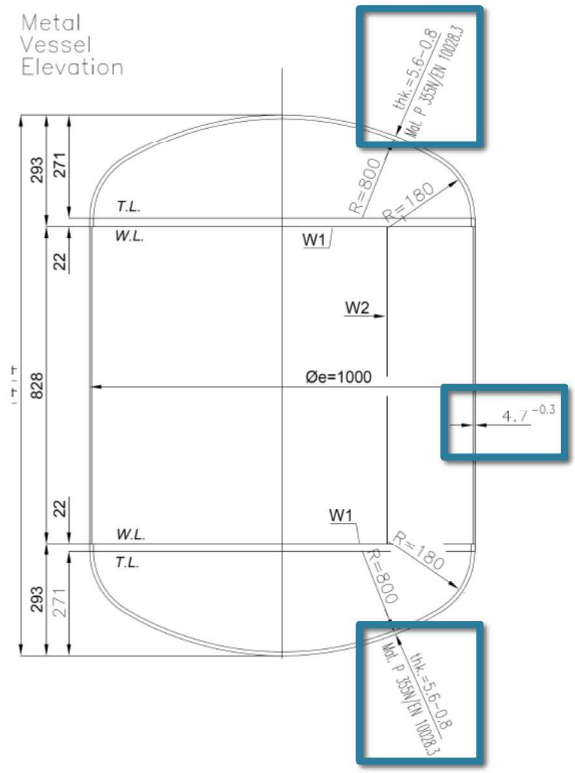
Real-time update of the syntethic index γ:

$$\gamma = h\left(ICSE, ISRE\right)$$

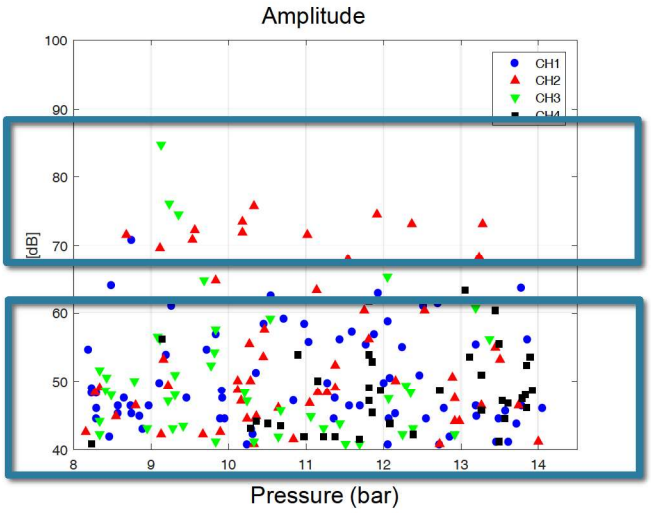
AE tank classification

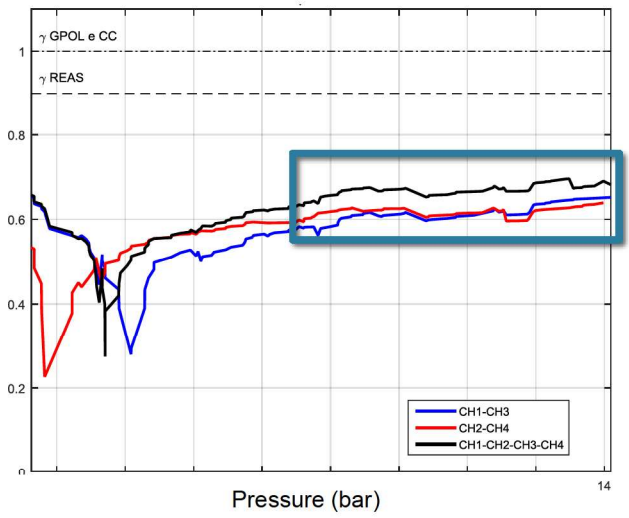
Class	Diagnosis	Condition	Tank classification
0	Not executed test	Accidental stop, problem with setup etc.	Not classifiable
1	Positive test	$\gamma_{max} \leq \gamma_{lim}$ (0.87)	Compliant
2	Negative test	$\gamma_{max} > \gamma_{lim}$ or precautionary stop	Not-compliant

TEST1 – Tank



Test 1 – A shell's thickness reduction of 0.9 mm; no artificial defects



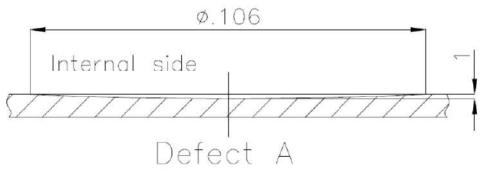


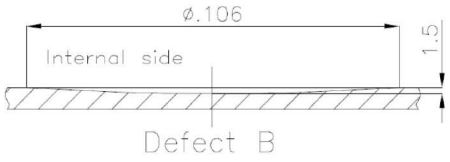
- Majority of AE events among 40 dB e 60 dB
- γ values always lower than γ_{lim}
- Limited differences among sensor combination
- Acoustic activity always within the acceptance limits according to the ISPESL procedure

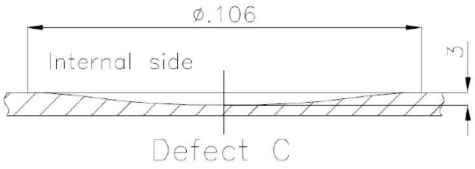
Sensor combination	γ_{max}	A75	A85	ACORR
1-2-3-4	0.70	3	0	55
1-3	0.65	4	0	70
2-4	0.64	2	0	61
Threshold	**0.87**	**25**	**8**	**1000**

CLASS 1
Compliant Tank

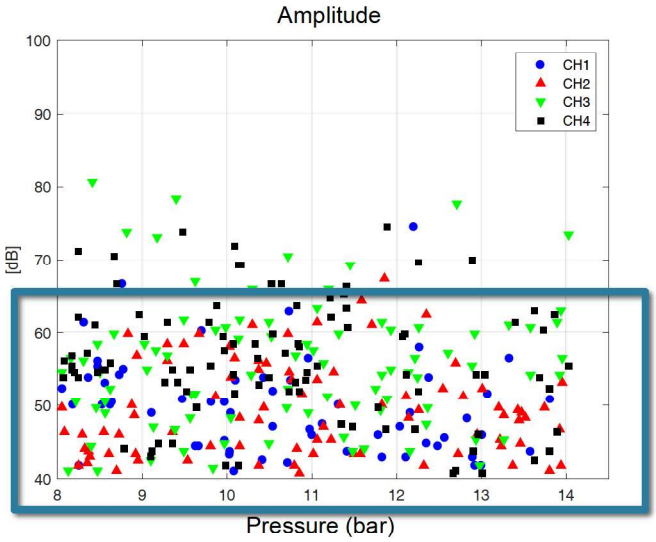
TEST2 – Tank

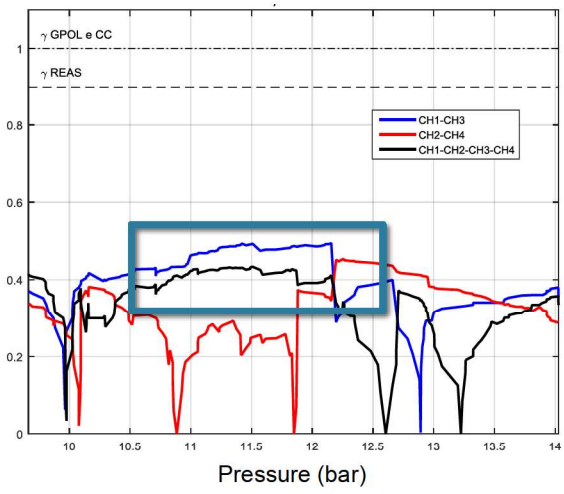






Test 2 – three thickness reductions from 1.0 to 3.0 mm on the shell



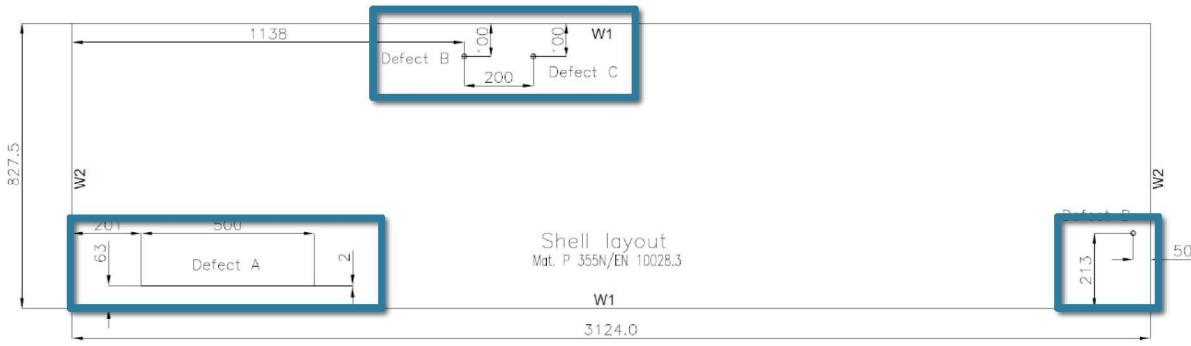


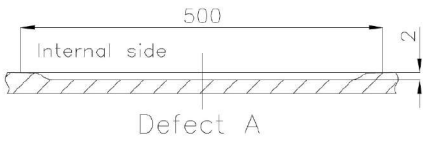
- Majority of AE events under 60 dB
- γ values always lower than γ_{lim}
- Limited differences among sensor combination
- Acoustic activity always within the acceptance limits according to the ISPESL procedure

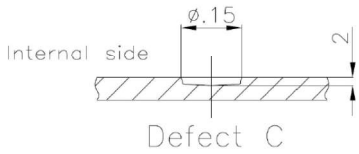
Sensor combination	γ_{max}	A75	A85	ACORR
1-2-3-4	0.43	3	0	8
1-3	0.49	3	0	18
2-4	0.45	0	0	16
Threshold	**0.87**	**25**	**8**	**1000**

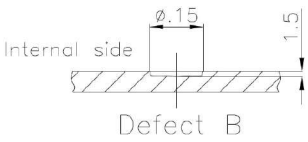
CLASS 1
Compliant Tank

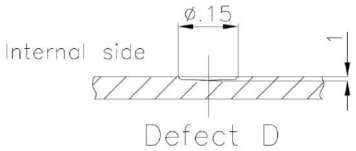
TEST3 – Tank



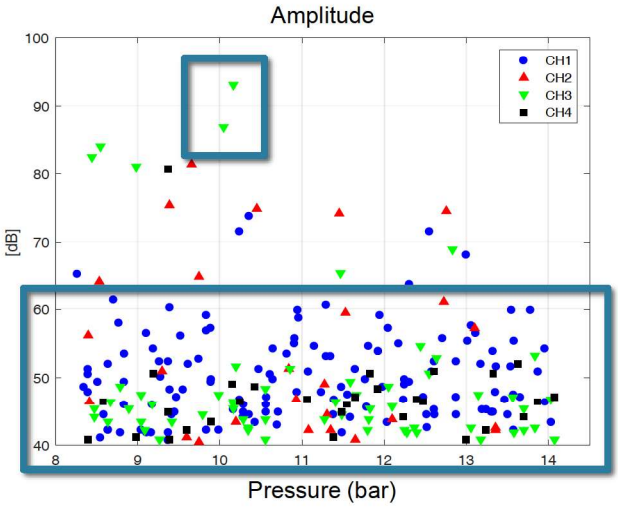


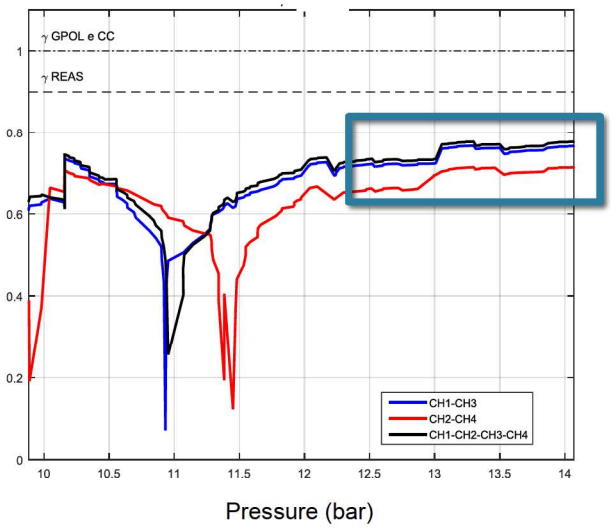






Test 3 – four thickness reductions from 1.0 to 2.0 mm on the shell



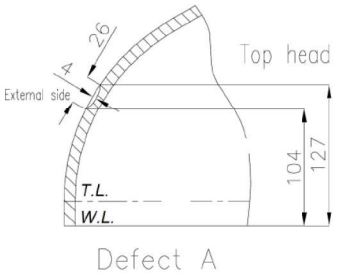


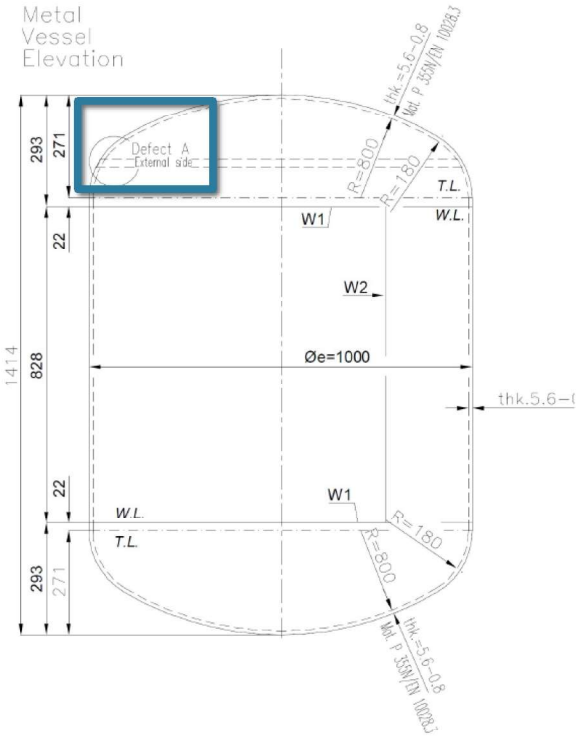
- Majority of AE events under 60 dB
- Two events greater than 85 dB
- γ values always lower than γ_{lim}
- Limited differences among sensor combination
- Acoustic activity always within the acceptance limits according to the ISPESL procedure

Sensor combination	γ_{max}	A75	A85	ACORR
1-2-3-4	0.78	8	2	38
1-3	0.77	10	2	76
2-4	0.71	8	2	51
Threshold	**0.87**	**25**	**8**	**1000**

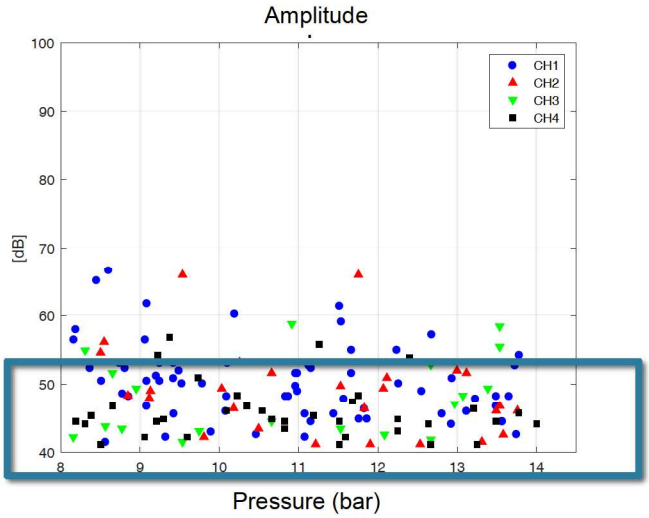
CLASS 1
Compliant Tank

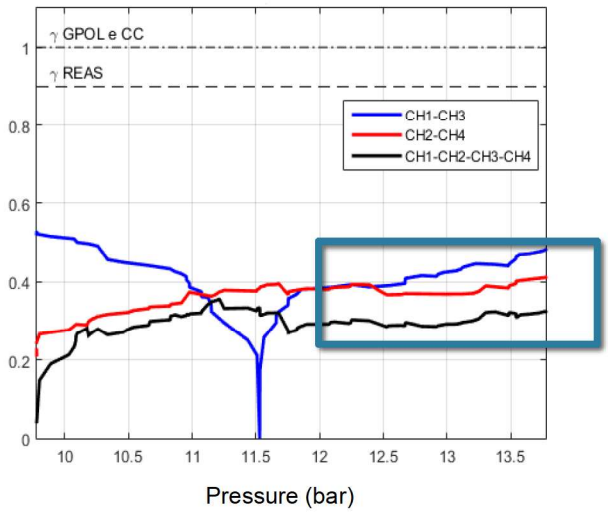
TEST4 – Tank





Test 4 – one thickness reduction on the superior end of the tank



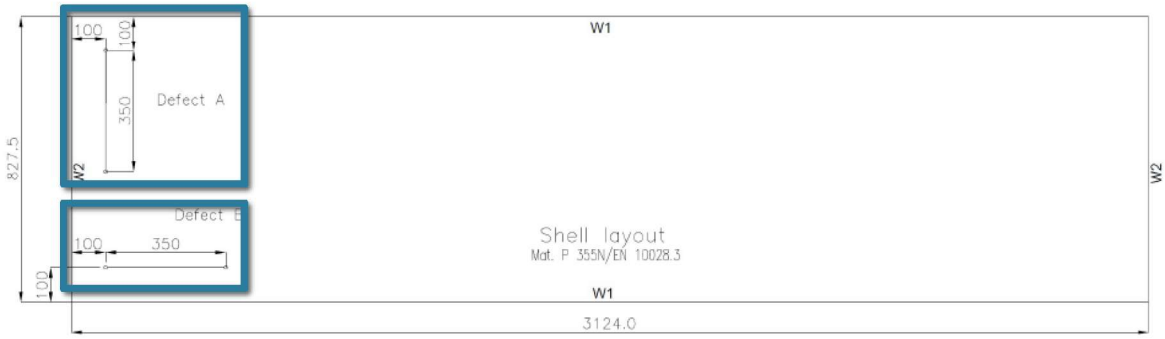


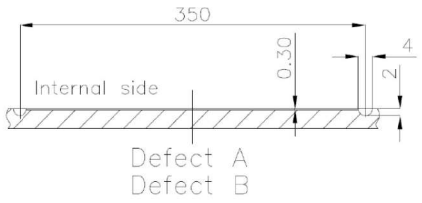
- Majority of AE events under 55 dB
- γ values always lower than γ_{lim}
- Limited differences among sensor combination
- Acoustic activity always within the acceptance limits according to the ISPESL procedure

Sensor combination	γ_{max}	A75	A85	ACORR
1-2-3-4	0.36	0	0	6
1-3	0.53	0	0	7
2-4	0.41	0	0	15
Threshold	**0.87**	**25**	**8**	**1000**

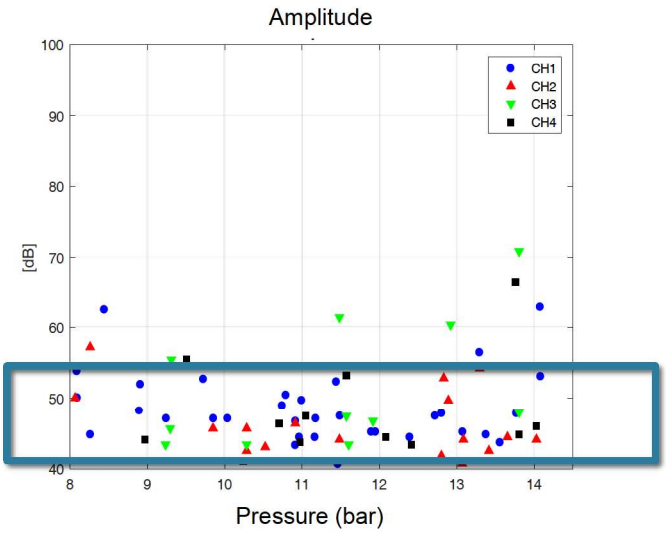
CLASS 1
Compliant Tank

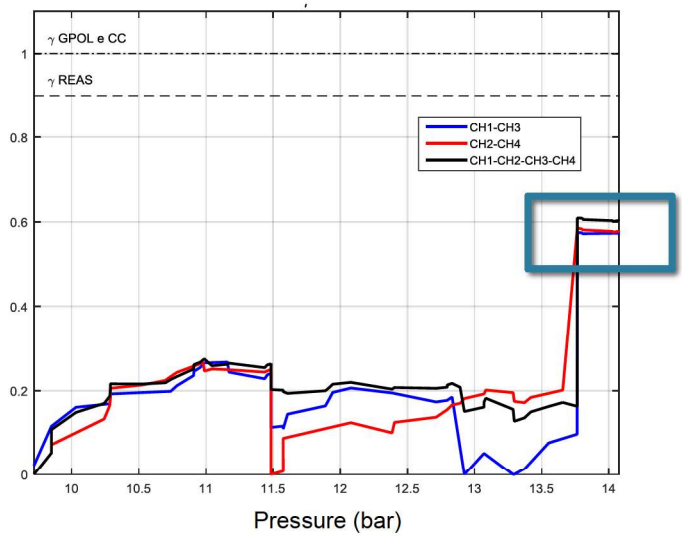
TEST5 – Tank





Test 5 – Two carvings with depth of 0.3 mm obtained by electro-discharge process





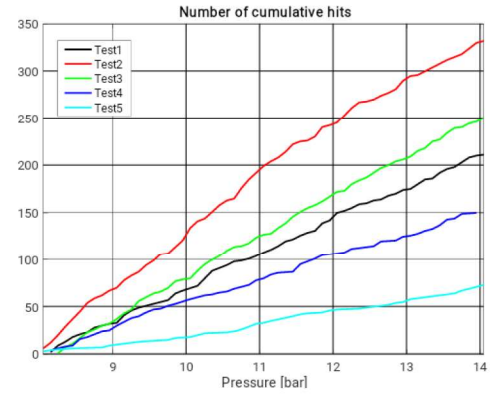
- Limited activity between 40 and 50 dB
- No events greater than 70 dB
- γ values always lower than γ_{lim}
- Limited differences among sensor combination
- Acoustic activity always within the acceptance limits according to the ISPESL procedure

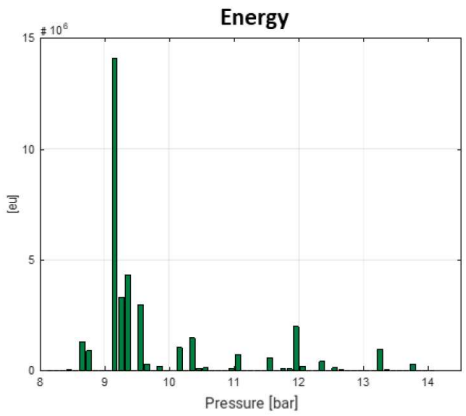
Sensor combination	γ_{max}	A75	A85	ACORR
1-2-3-4	0.61	0	0	7
1-3	0.57	0	0	12
2-4	0.59	0	0	23
Threshold	**0.87**	**25**	**8**	**1000**

CLASS 1
Compliant Tank

Propose two further indices:

- b: angular coefficient of the linear regression curve between cumulative hits and pressure
- AUC_E: trapezoidal numerical integration of the energy curve





Tank	b (bar^{-1})	AUC_E (eu bar)	γ_{max}
TEST1	35.39	$3.60\ 10^6$	0.70
TEST2	54.88	$4.34\ 10^4$	0.43
TEST3	42.97	$2.01\ 10^7$	0.78
TEST4	24.75	$3.38\ 10^3$	0.36
TEST5	11.91	$4.22\ 10^4$	0.61

- Greater values of b is not related to greater γ_{max}
- Qualitative correlation between AUC_E and γ_{max}

Conclusions

- Different locations of AE sensors do not influence the final classification
- All realized defects generate acoustic activity in the limits of acceptance according the ISPESL procedure
- γ_{max} related to TEST1 and TEST3 more than 50% with respect to the other tanks
- Results related to AUC_E open the possibility to use it as useful index

- *Increase the number of tanks*
- *Statistical analysis on different sensors locations*
- *Correlation AUC_E index*
- *Comparison with other NDT*

Any question?

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