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Structural Damage Location by Low-Cost Piezoelectric Transducer and Advanced Signal Processing Techniques

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- *The development of new low-cost transducers and systems has been extensively aimed in both industry and academia to promote a correct failure diagnosis in aerospace, naval and civil structures.*

- *Structural health monitoring (SHM) engineering is focused on promoting human safety and reduction of maintenance costs of these components.*

- *Traditionally, SHM aims to detect structural damages at the initial stage, before it reaches a critical level of severity. One of the most promising damage location technique is based on the triangulation of acoustic waves (AE).*

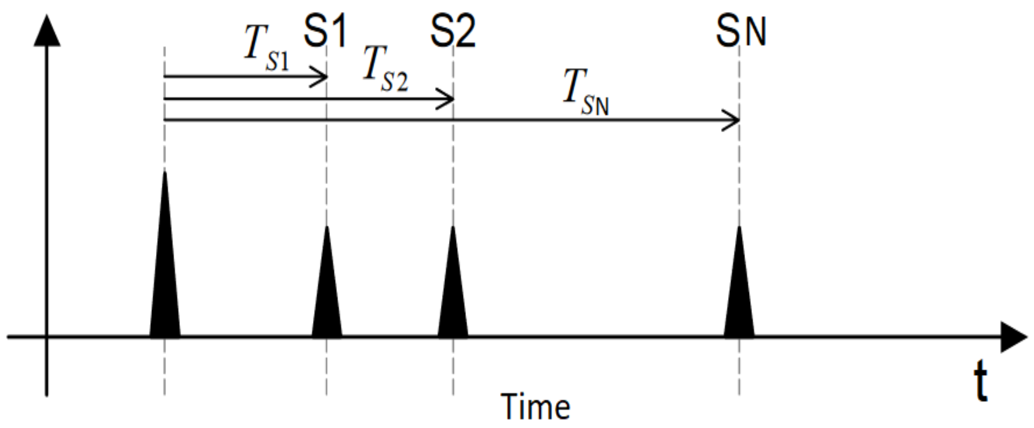
Triangulation Concept

- *A set of piezoelectric transducers is attached on a host structure in order to capture the acoustic waves produced by failures or cracks.*
- *The damage location is performed by a mathematical model which uses the difference of the time of arrival (TOA) of the signals and the wave velocity propagation in the component.*
- *Although this method may be simple, the detection of TOA requires complex statistical and signal processing techniques.*

Triangulation Concept

- *The triangulation concept measures the wave travelling time using a set of different located sensors assembled into a damaged structure.*
- *For each sensor I, attached on a host strucuture, for 1 < i < n, the mathematical model is given by:*

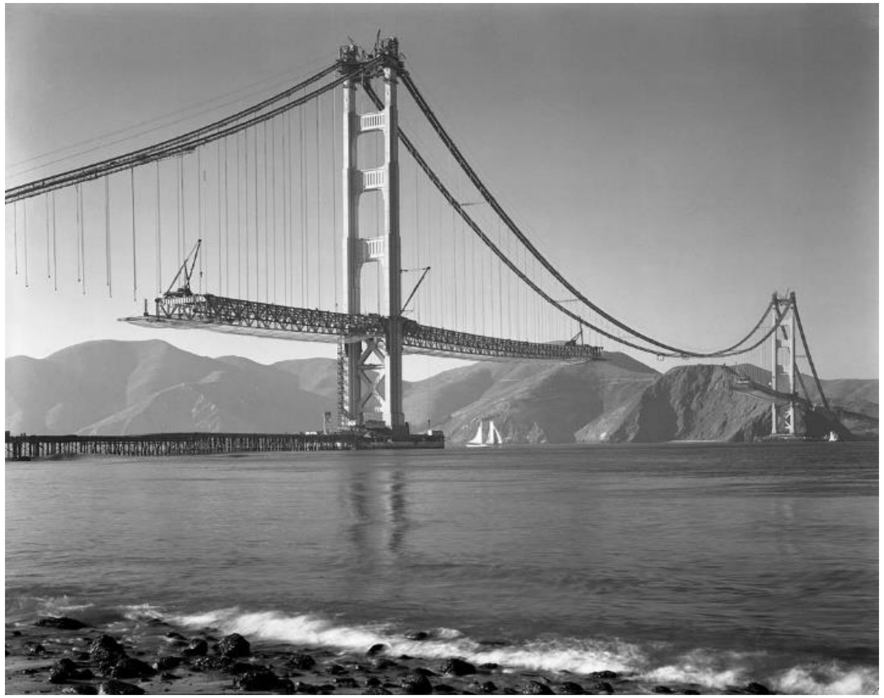
$$\begin{cases} (x-x_{si})^2+(y-y_{si})^2+(z-z_{si})^2-(V\cdot T_{si})^2=0, \\ T_{s1}-T_{si}-\Delta t_i=0, \end{cases}$$



- *Hinkley criterion (HC) (Eq. 1) and Akaike information criterion (AIC) (Eq. 2) are algorithms used for acoustic wave characterization in which energy and frequency values can vary in a wide range. The local minimum of both curves are the TOA of the AE signal.*

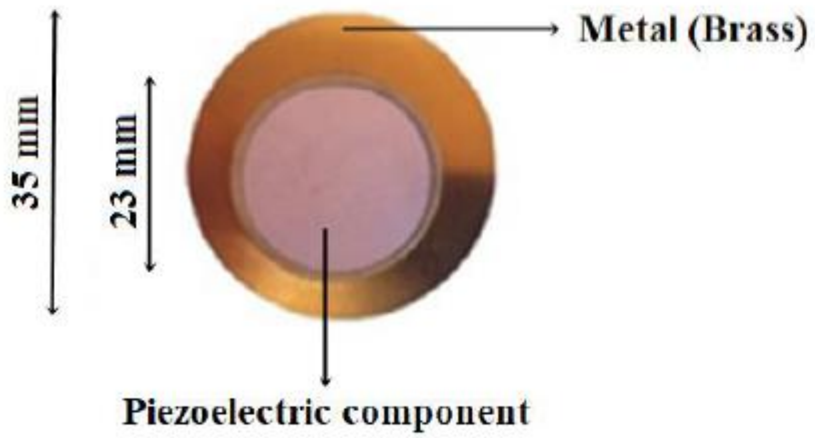
$$H(k) = \sum_{k=0}^{N} y[k]^2 - \frac{S_N}{N} \qquad (1)$$

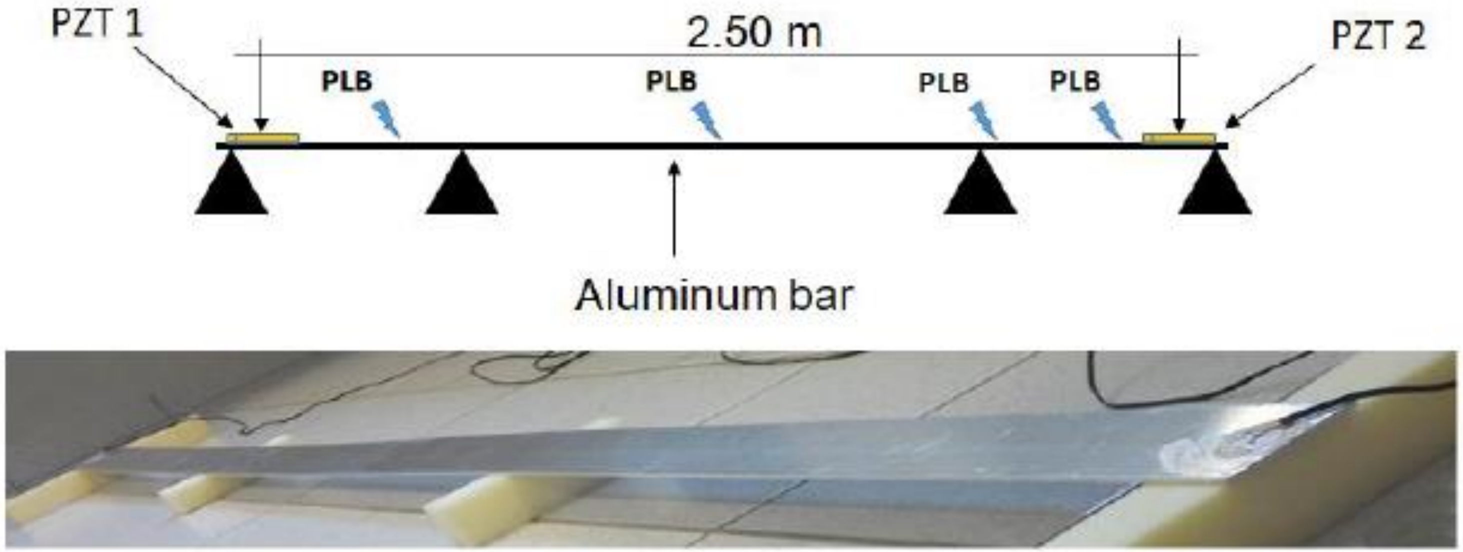
$$AIC(k) = k ln(\sigma^2_{(1,k)}) + (N - k - 1) ln(\sigma^2_{(k+1,N)}) \qquad (2)$$



- *Based on this, this work presented a comparative study between the application of Akaike and Hinkley criteria for TOA determination using low-cost piezoelectric diaphragms.*

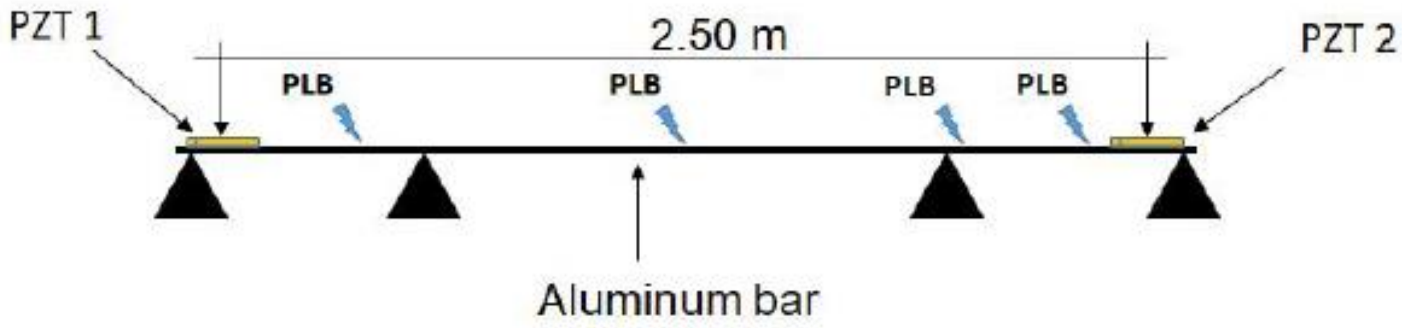
- Two piezoelectric diaphragms (PZT1 and PZT2) were positioned, one in each end, on an aluminum beam (2,5 m x 0,075 m x 0,003 m) using cyanoacrylate glue;
- Damages in the surface were created in four different locations on the beam’s surface using the pencil lead break (PLB) test;
- A mechanical pencil is pushed against a material until the breakage of the graphite. The pushing generates an instantaneous damage and, as consequence, a microscopic displacement of mass;
- After each pushing, TOA from each sensor was acquired and evaluated using Hinkley and Akaike criteria. Figure 2 depicts the experiment procedure.

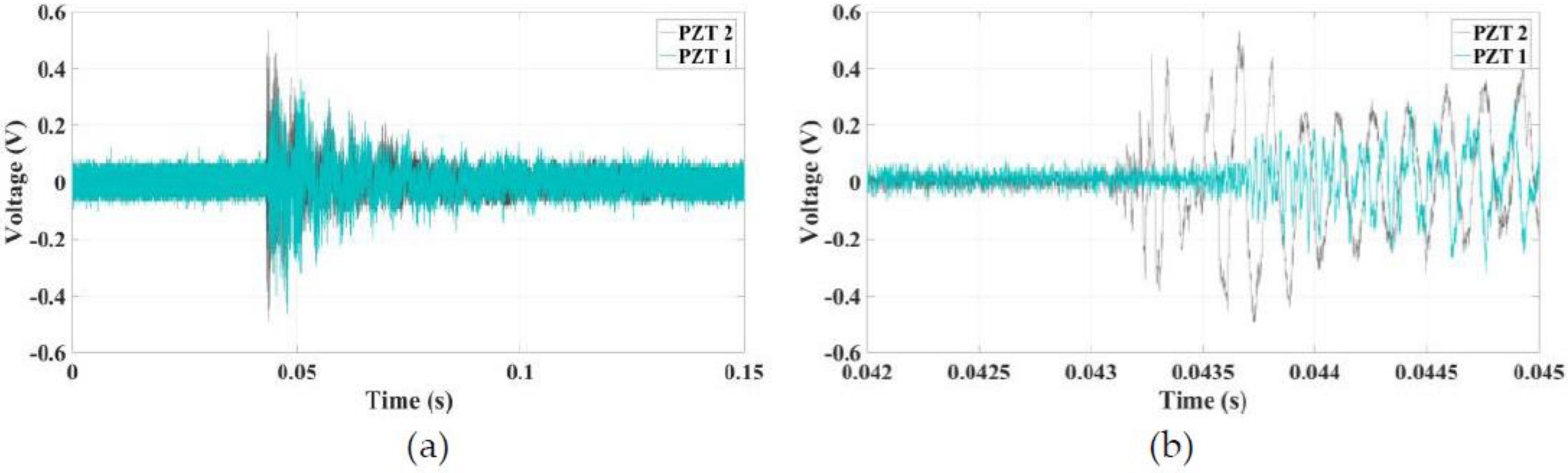

Metal (Brass)
35 mm
23 mm
Piezoelectric component


PZT 1
2.50 m
PZT 2
PLB
PLB
PLB
PLB
Aluminum bar

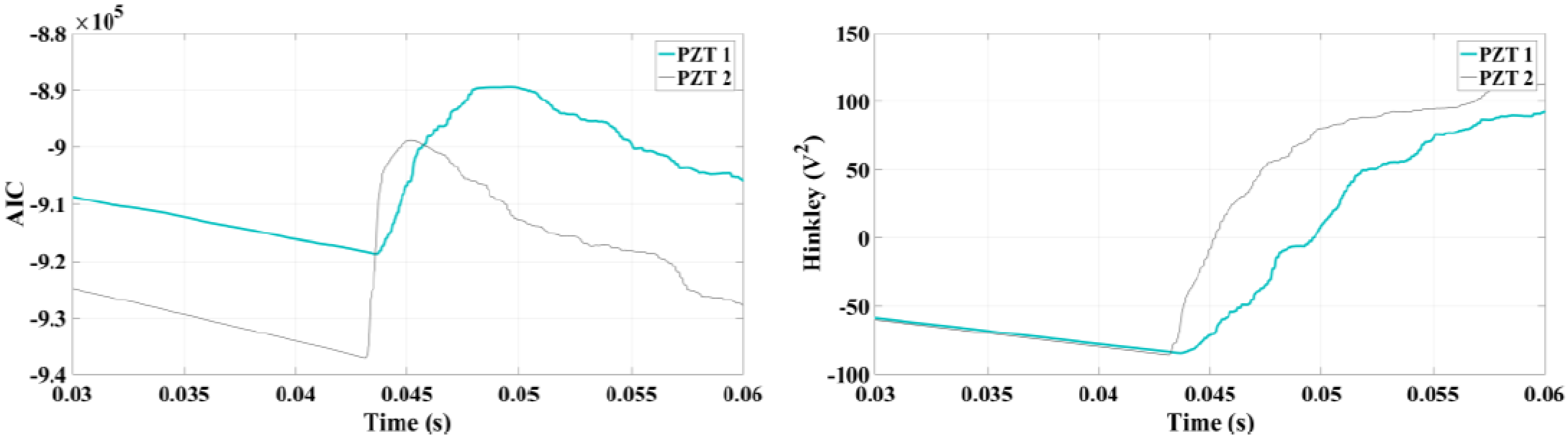
Mathematical Model

$$\begin{cases} x - V_{Al} \cdot t_1 = 0 \\ x + \left(V_{Al} \cdot t_2\right) - 2.5 = 0 \\ t_2 - t_1 - \Delta t_{2,1} = 0 \end{cases}$$





Signals to disturbance at 0.5 m: (**a**) Total duration; (**b**) Zoom.



(a) (b)

Signal analyzed for damage at *x* = 0.5 m: (**a**) via Hinkley; (**b**) via Akaike.

Damage location using Hinkley and Akaike criteria.

Real Damage Position (m)	Position Akaike (m)	Position Hinkley (m)	Error Akaike (%)	Error Hinkley (%)
0.5	0.47	0.42	6	16
1.25	1.25	1.21	0	3.2
2	2.03	2.04	1.5	2
2.5	2.49	2.52	0.4	0.8

- *The differences in the excitation times caused by acoustic waves propagating in an aluminum beam instrumented with low-cost piezoelectric diaphragms were analyzed to compare both methods. The results have shown that the piezoelectric diaphragms are reliable, and Akaike criterium was more precise than Hinkley to locate damage.*

Thank you!

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