Damage detection in a population of similar composite beams using stochastic methods

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The Problem

- The vibration-based Structural Health Monitoring for a population of composite structures under manufacturing variability and non-measurable excitation.

Goals

- Damage diagnosis including the detection, location and size characterization of incipient cracks in a population of nominally identical composite beams with varying thickness, through advanced vibration-based stochastic methods.

Concluding Remarks

- The detection of cracks was successful using both employed methods.
- The PCA-MM-TF-ARX-OLS method demonstrated superior performance in determining cracks at position 1, as well as in distinguishing between crack size of 2 cm and 3 cm. Conversely, the PCA-MM-TF-ARX-IV method exhibited stronger performance in identifying cracks at position 2 and in discerning crack sizes of 1 cm.

Parametric Modelling

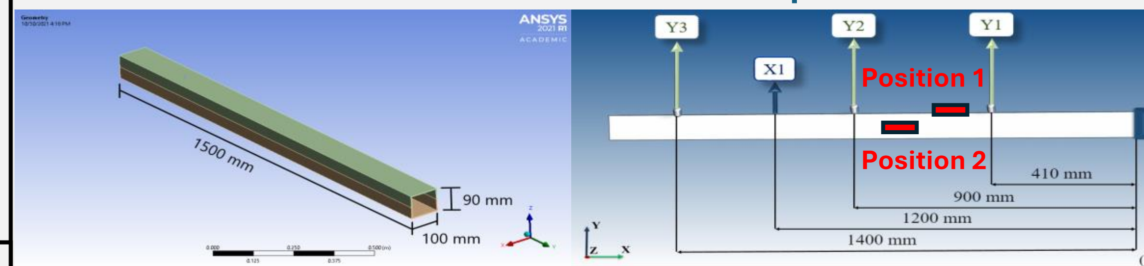
The parameters of the stochastic models 1) TF-ARX-OLS 2)TF-ARX-IV are employed as the characteristic quantity:

- **TF-ARX Models** $y_1[t] + \sum_{i=1}^{n_a} a_i \cdot y_1[t-i] = \sum_{i=0}^{n_b} b_i \cdot y_2[t-i] + e[t]$

1) **Ordinary Least Square** $\widehat{\boldsymbol{\theta}}_{OLS} = \left(\frac{1}{N}\sum_{t=0}^{N-1} \boldsymbol{\varphi}[t] \cdot \boldsymbol{\varphi}^T[t]\right)^{-1} \cdot \left(\frac{1}{N}\sum_{t=0}^{N-1} \boldsymbol{\varphi}[t] \cdot y_1[t]\right)$

2) **Instrumental Variables** $\widehat{\boldsymbol{\theta}}_{IV} = \left(\frac{1}{N}\sum_{t=0}^{N-1} \boldsymbol{\zeta} \cdot \boldsymbol{\Phi}_{\kappa}^T\right)^{-1} \cdot \left(\frac{1}{N}\sum_{t=0}^{N-1} \boldsymbol{\zeta} \cdot y_1\right)$

The Finite Element Model of the Composite Structure



Damage Type (Through-the-thickness crack)	
Damage	**Damage Length**
Small Damage	10mm
Medium Damage	30mm
Large Damage	50mm

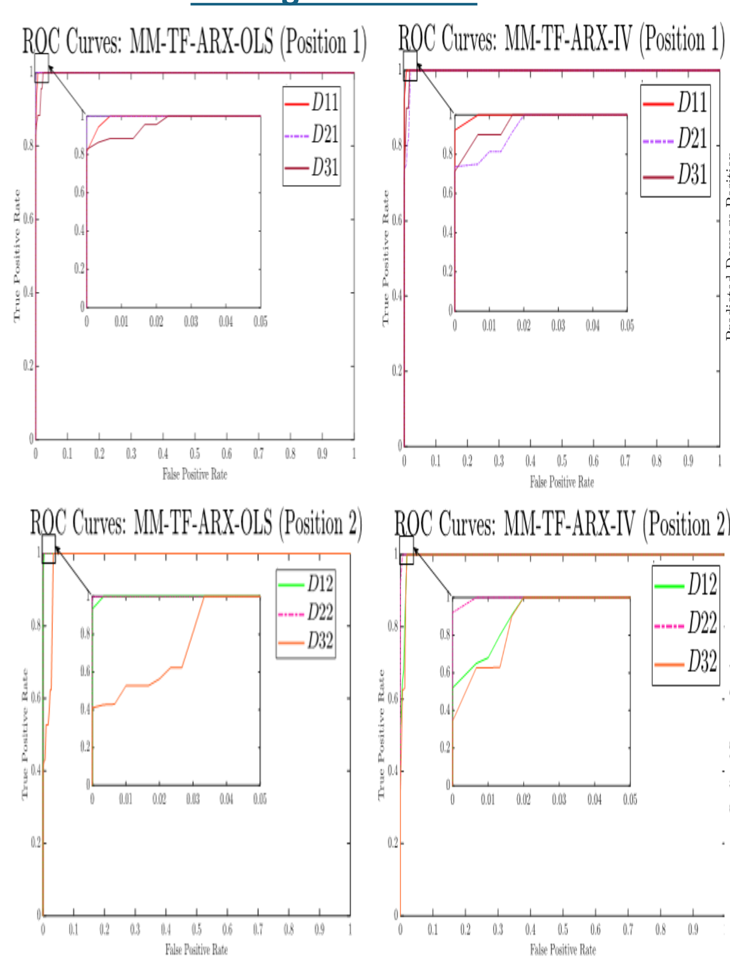
Turbulence-like excitation is implemented via a second-order system including also harmonics (434 Hz) simulating the effects of rotating parts. Fs = 1 250 Hz; Signal Length: N = 5002 samples

The Monte-Carlo Numerical Experiments

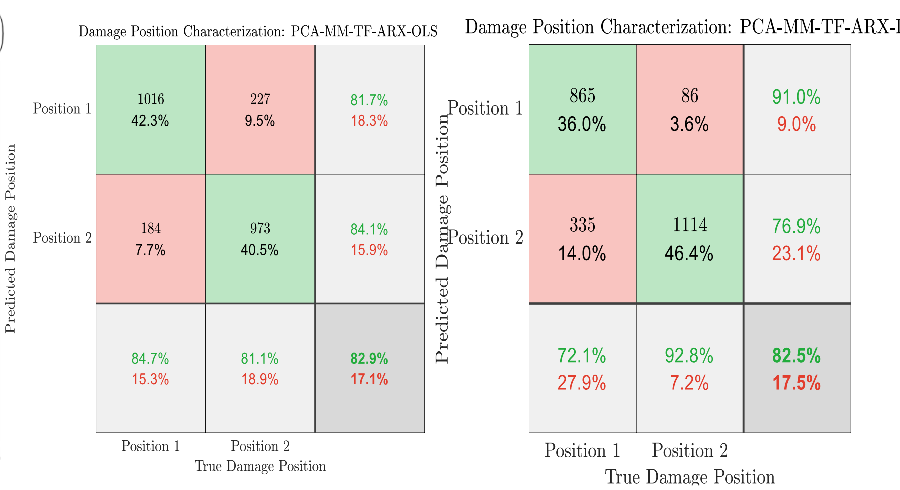
Structural Health State	Damage Position	Number Of Structures	Number Of Experiments Per Structure	Total Number Of Experiments
Healthy (H)	----	42	1	42
Small Damage (D11)	Position 1	12	1	12
Small Damage (D12)	Position 2	12	1	12
Medium Damage (D21)	Position 1	12	1	12
Medium Damage (D22)	Position 2	12	1	12
Large Damage (D31)	Position 1	12	1	12
Large Damage (D32)	Position 2	12	1	12

Damage Detection, Position determination and Size characterization

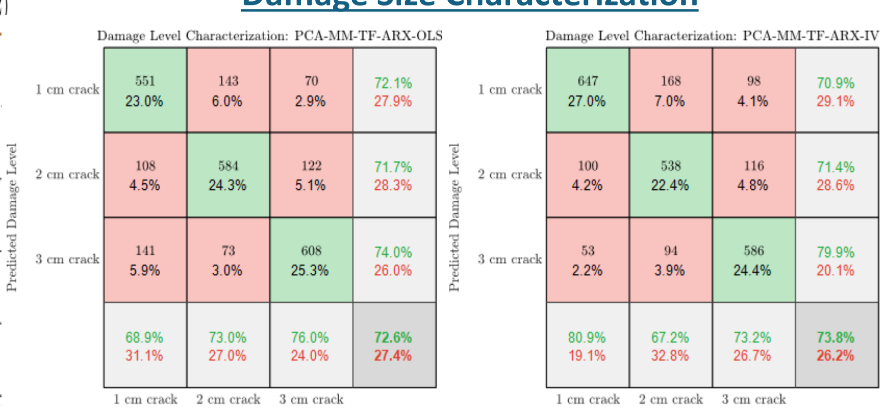
Damage Detection



Damage Position Determination



Damage Size Characterization



Uncertainty/Damage Effects on Dynamics