

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

Stephanopoulos Apollon I.D.: 1047233

University of Patras

Department of Mechanical Engineering and Aeronautics

Stochastic Mechanical Systems and Automation Laboratory

Supervisor: I. Sakellariou, Associate Professor



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** $\hat{\theta}_{OLS} = \left(\frac{1}{N} \sum_{t=0}^{N-1} \phi[t] \cdot \phi^T[t] \right)^{-1} \cdot \left(\frac{1}{N} \sum_{t=0}^{N-1} \phi[t] \cdot y_1[t] \right)$

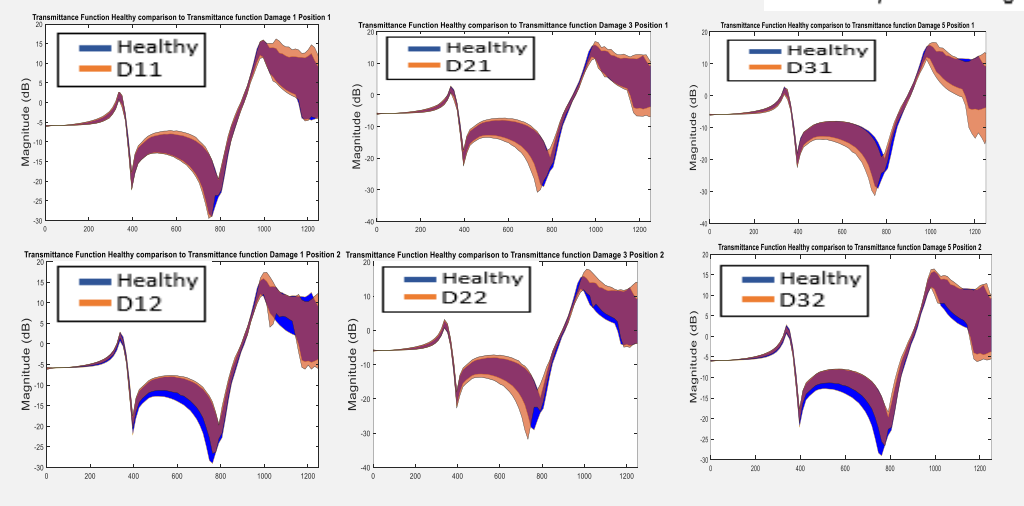
2) **Instrumental Variables** $\hat{\theta}_{IV} = \left(\frac{1}{N} \sum_{t=0}^{N-1} \zeta \cdot \Phi_K^T \right)^{-1} \cdot \left(\frac{1}{N} \sum_{t=0}^{N-1} \zeta \cdot y_1 \right)$

The Monte-Carlo Numerical Experiments

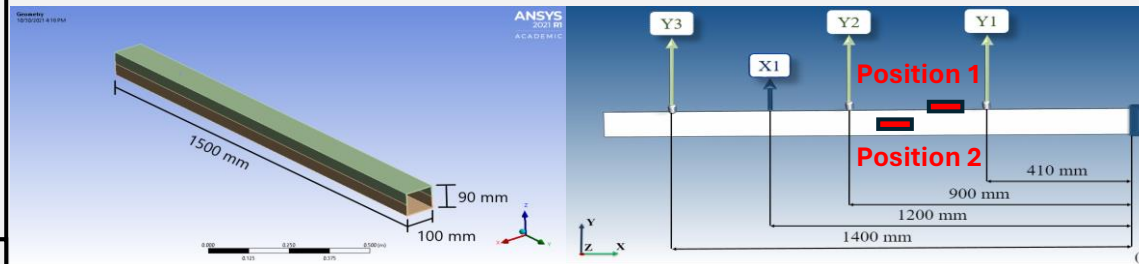
Structural Health State	Damage Position	Number Of Structures	Number Of Experiments Per Structure	Total Number Of Experiments
Healthy (H)	----	42	1	42
Small Damage (D11)	Position 1	12	1	12
Small Damage (D12)	Position 2	12	1	12
Medium Damage (D21)	Position 1	12	1	12
Medium Damage (D22)	Position 2	12	1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

Uncertainty/Damage Effects on Dynamics

— Healthy — Damage



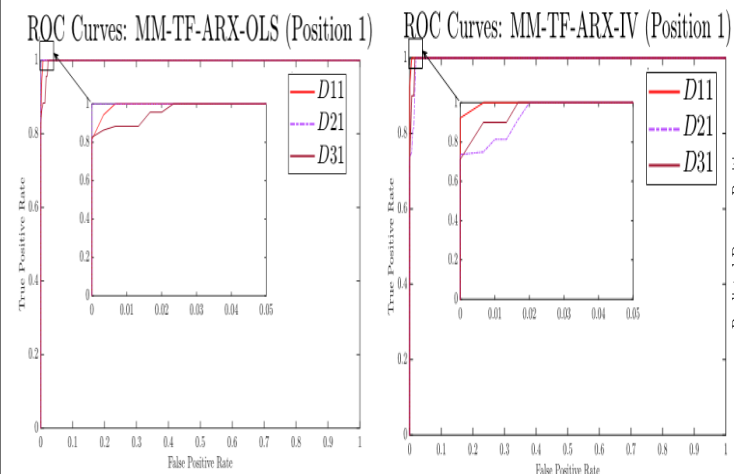
The Finite Element Model of the Composite Structure



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

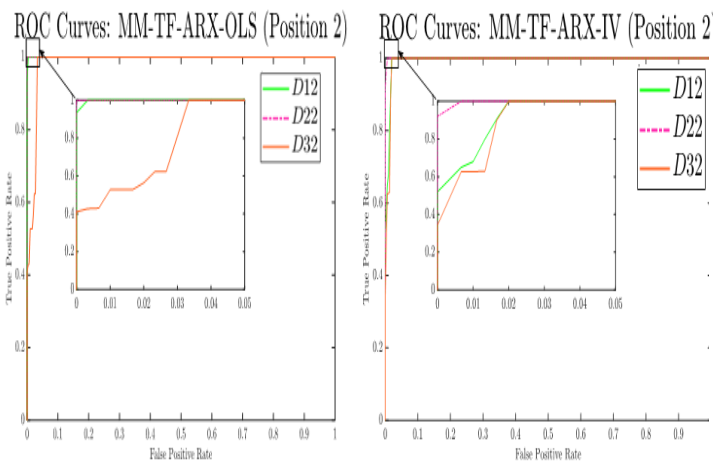
Damage Detection, Position determination and Size characterization

Damage Detection



Damage Position Determination

Damage Position Characterization: PCA-MM-TF-ARX-OLS				Damage Position Characterization: PCA-MM-TF-ARX-IV				
Predicted Damage Position	Position 1	1016 42.3%	227 9.5%	81.7% 18.3%	Position 1	865 36.0%	86 3.6%	91.0% 9.0%
	Position 2	184 7.7%	973 40.5%	84.1% 15.9%	Position 2	335 14.0%	1114 46.4%	76.9% 23.1%
		84.7% 15.3%	81.1% 18.9%	82.9% 17.1%		72.1% 27.9%	92.8% 7.2%	82.5% 17.5%
	Position 1	Position 2			Position 1	Position 2		
	True Damage Position				True Damage Position			



Damage Size Characterization

Damage Level Characterization: PCA-MM-TF-ARX-OLS					Damage Level Characterization: PCA-MM-TF-ARX-IV					
Predicted Damage Level	1 cm crack	551 23.0%	143 6.0%	70 2.9%	72.1% 27.9%	1 cm crack	647 27.0%	168 7.0%	98 4.1%	70.9% 29.1%
	2 cm crack	108 4.5%	584 24.3%	122 5.1%	71.7% 28.3%	2 cm crack	100 4.2%	538 22.4%	116 4.8%	71.4% 28.6%
	3 cm crack	141 5.9%	73 3.0%	608 25.3%	74.0% 26.0%	3 cm crack	53 2.2%	94 3.9%	586 24.4%	79.9% 20.1%
		68.9% 31.1%	73.0% 27.0%	76.0% 24.0%	72.6% 27.4%		80.9% 19.1%	67.2% 32.8%	73.2% 26.7%	73.8% 26.2%
	1 cm crack	2 cm crack	3 cm crack		1 cm crack	2 cm crack	3 cm crack			
True Damage Level					True Damage Level					