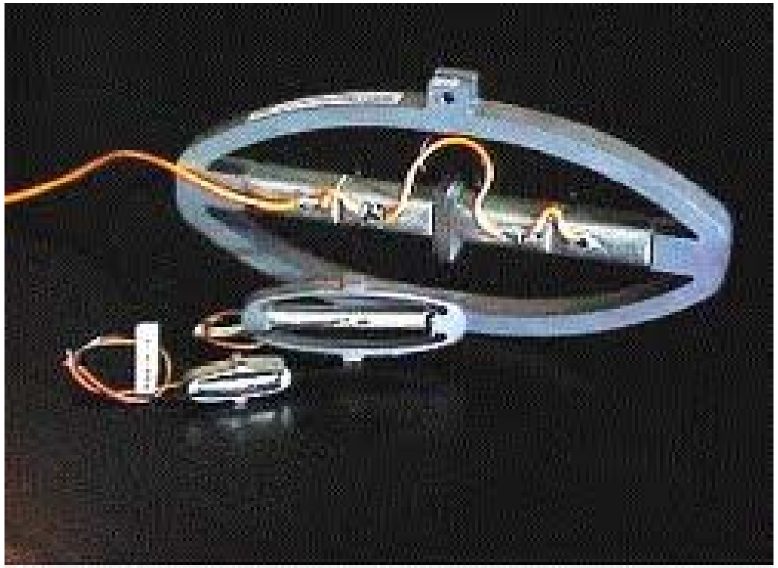

APA230L, APA150M, APA100S

Module 5: Actuators & Sensors based on HBLS Smart Materials

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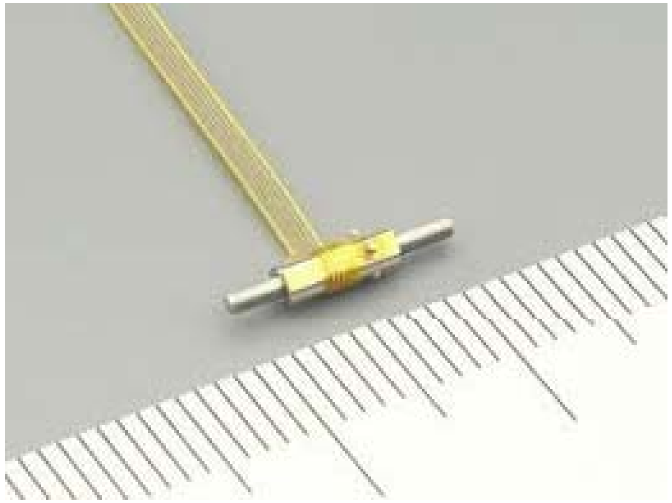
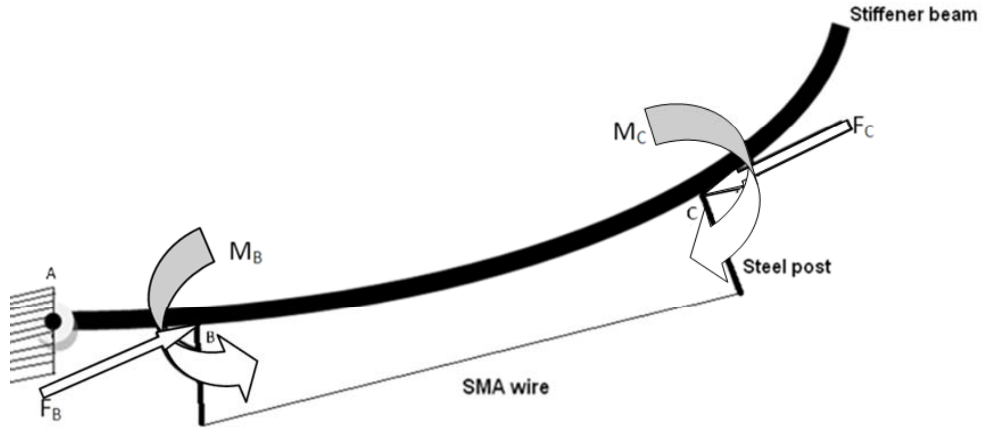


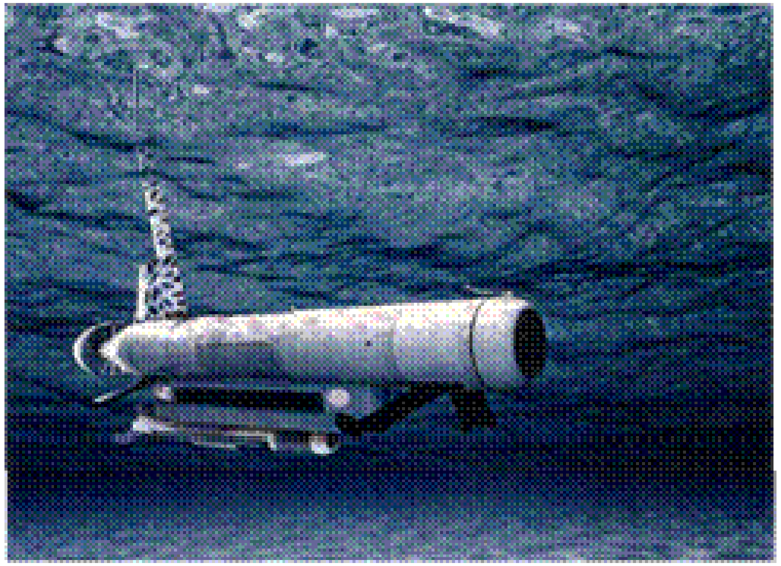


LECTURE 36
Delamination Sensing and Vibration Control using Magnetostrictive Materials
(Part 2)

Organization of this Lecture

- Symmetric Laminate with Magnetostrictive Sensor
- Asymmetric Laminate with Magnetostrictive Sensor
- Sensing Delamination: Results of Numerical Analysis

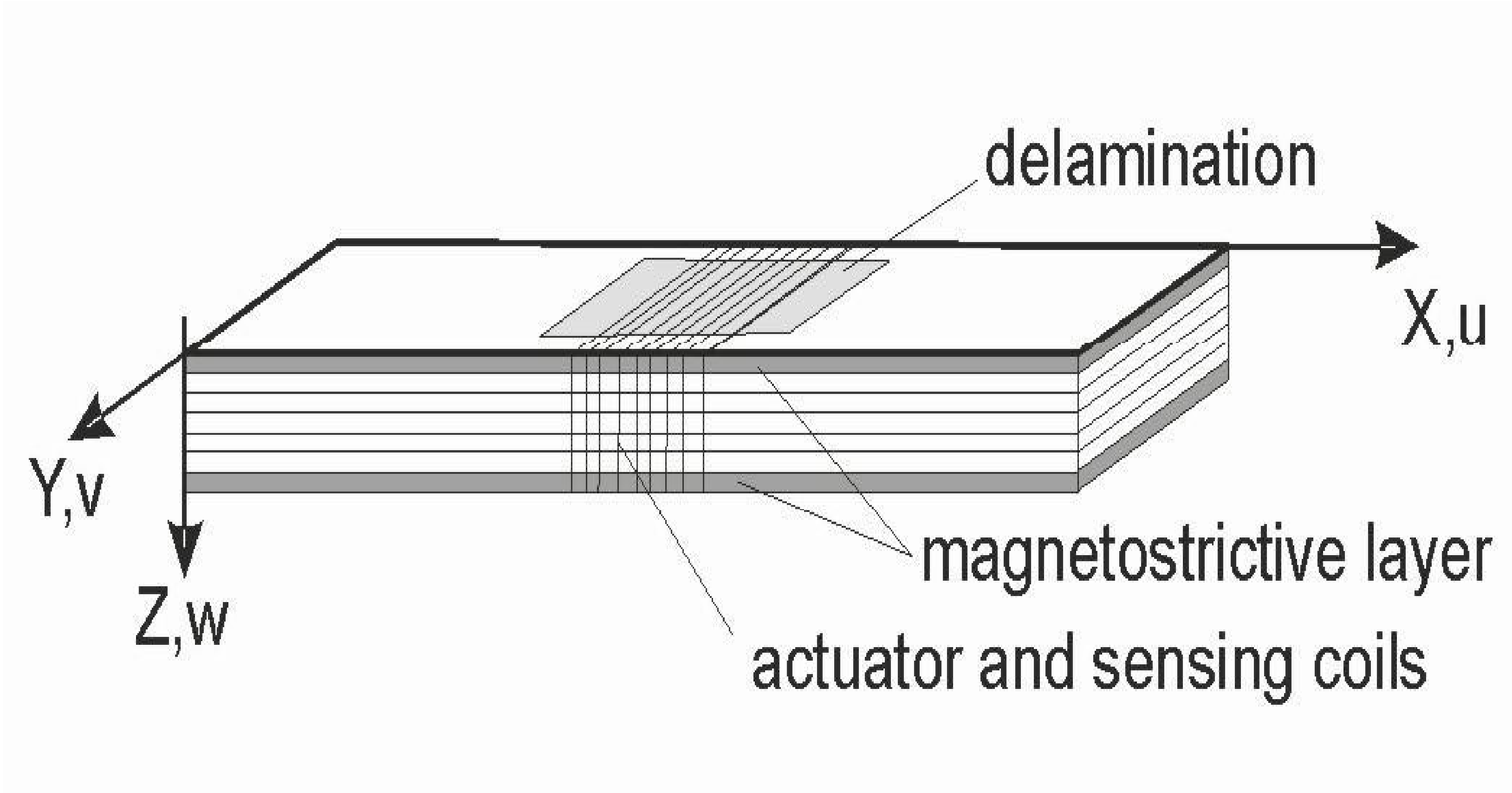
Magnetostrictive Material: High Bandwidth-Moderate Strain Actuation



- **DC to 3 KHz Bandwidth**
- **Force availability reported up to 1700 N**
- **Free Strain: 3000 micron**

TALON (Tactical Acoustic Littoral Ocean Network) sonar system uses Magnetostrictive Terfenol-D for under-water submarine detection, source: Etrema Products

Smart laminate beam



Symmetric/Asymmetric laminate

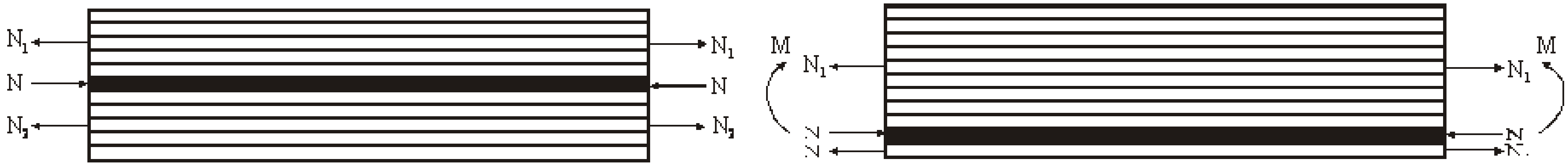


Fig 1 (a) Forces on the symmetric beam (b) Moment on asymmetric beam due to stresses induced in the magnetostrictive layer

Net Force in magnetostrictive layer (Compressive) $N = \sigma \, h_m$

Forces in upper & lower segment $N_1 = A_1 \varepsilon$ & $N_2 = A_2 \varepsilon$

If no external force is applied

$$\alpha = \frac{dN}{\left[\dfrac{h_m}{A_1 + A_2} - S^H\right]}$$

N= N1+N2

Strain ε = N/ A1+A2

Stress $\sigma = \alpha \, I$

Asymmetric composite laminate (…contd..)

Moment on the beam due to stresses induced in the magnetostrictive layer

$M = N_1 a + N_2 c - Nb$

Mid plane curvature

$$\lambda = \frac{M - B\varepsilon}{D}$$

Axial strain/stress in magnetostrictive layer including the effect of bending

$$\varepsilon' = \varepsilon - z_k \lambda$$

$$\sigma' = \frac{1}{S}\left[\varepsilon' - dnI_0 \sin \omega t\right]$$

Failure criterion (Griffith's)

Delamination will be initiated when stress intensity factor K_I exceeds critical stress intensity factor K_{IC}

$$K_I \geq \beta \,.\, K_{IC}$$

$$K_I = \sigma\sqrt{\pi . C}$$

Failure criterion (Tsai-Wu)

$$F_1\sigma_1 + F_{11}\sigma_1^2 + F_2\sigma_2 + F_{22}\sigma_2^2 + 2F_{12}\sigma_1\sigma_2 + F_{66}\tau_{12}^2 = 1$$

$$F_1 = 1/X_\tau + 1/X_\varsigma \qquad F_{11} = -1/X_\tau X_\varsigma$$

$$F_2 = 1/Y_\tau + 1/Y_\varsigma \qquad F_{22} = 1/Y_\tau Y_\varsigma$$

$$F_{66} = 1/S^2$$

Voltage analysis

Symmetric laminate

$$B = \left(d\alpha + \mu N\right) I$$

$$V = -nla_r\left(d\alpha + \mu N\right) I_0 \omega \cos \omega t$$

Asymmetric laminate

without mechanical loading

$$V' = -nla_r\left(d\alpha' + \mu N\right) I_0 \omega \cos \omega t$$

with mechanical loading

$$V'' = -nla_r\left[d\left[\bar{Q}\right]\left(\varepsilon_0' + z_k \lambda'\right) + \mu n I_0 \right] \omega \cos \omega t$$

Table 1: Numerical details used in analysis

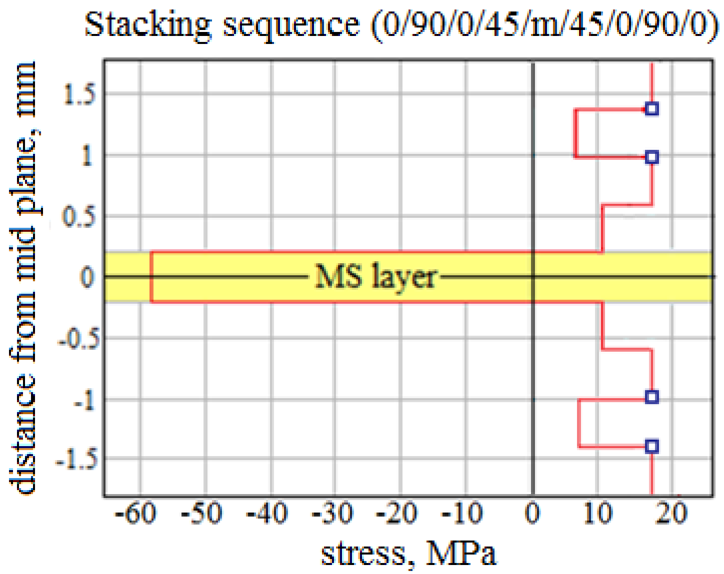
Number of plies including MS layer	9
Symmetric laminate stacking	[0/90/0/45/m/45/0/90/0]
Asymmetric laminate stacking	[0/90/0/45/0/90/m/90/0]
Composite used	carbon - epoxy
Elastic modulus of carbon fibers	350 GPa
Elastic modulus of epoxy matrix	3.50 GPa
Elastic modulus of Terfenol- D	30 GPa
Volume fraction of fiber	0.16
Volume fraction of Terfenol-D	0.0224
Poisson's ratio of carbon fiber	0.3
Poisson's ratio of epoxy matrix	0.4
Poisson's ratio for Terfenol-D	0.25

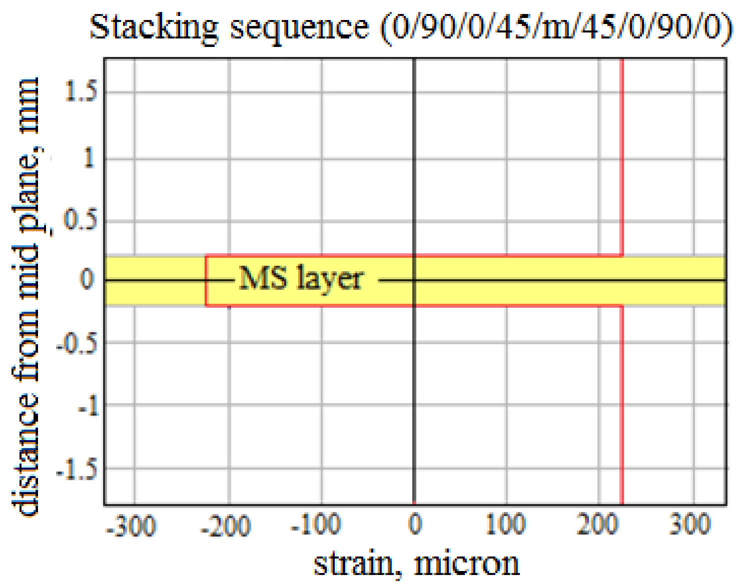
Table 1: Numerical details (…Contd.)

Number of turns in the coil per meter length of beam	1000
Carrier frequency	1000Hz
Carrier current	0.4 A
Piezomagnetic coefficient	1.5 e^{-8} m/A
Permeability	14.13e^{-7}
Coupling coefficient of Terfenol-D	0.75
Tensile strength of Terfenol-D	28 MPa
Compressive strength of Terfenol-D	700 MPa
Fracture toughness of MS layer	30 MPa-$m^{1/2}$
Size of crack at delamination	2 mm
Length of beam	100 mm
Width of over all beam structure	20 mm
Thickness of composite lamina	0.4 mm
Thickness of MS layer	0.4 mm

Results of analysis

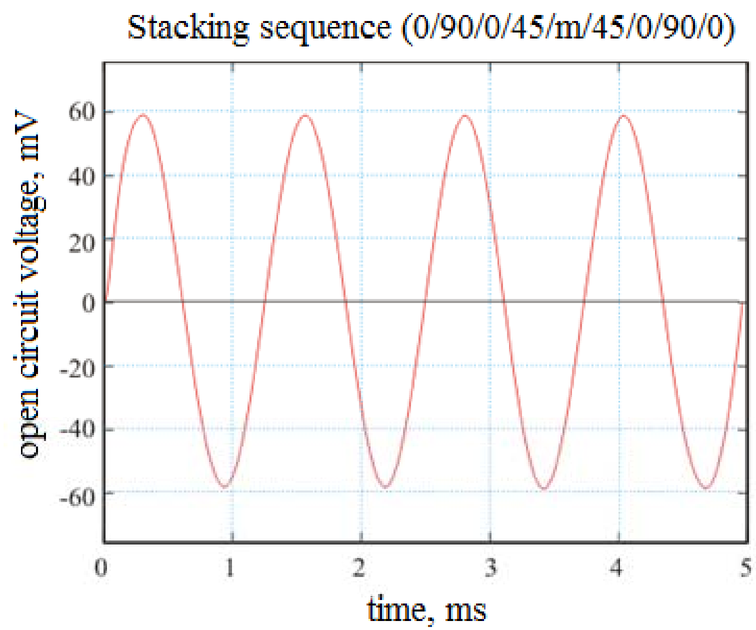
Stress and strain variations at various interfaces and in MS layer (actuator current only)





Symmetric laminate

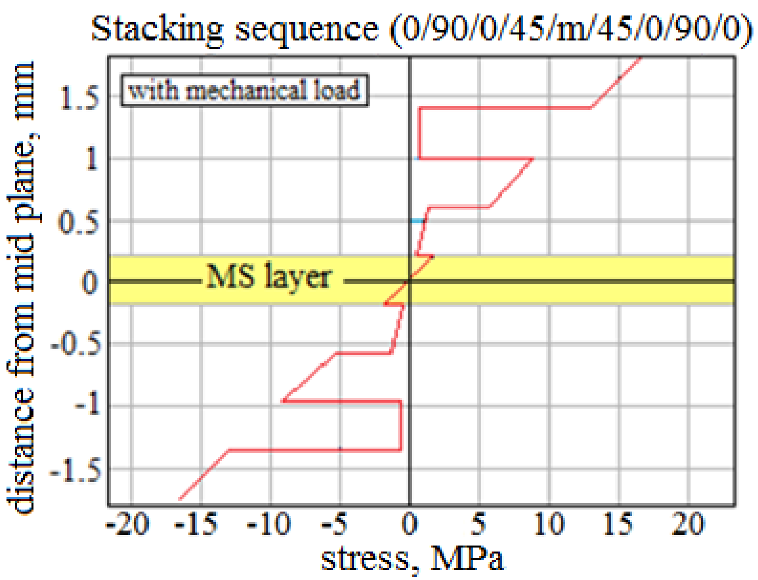
Open circuit voltage in MS layer at the time of delamination (actuator current only)

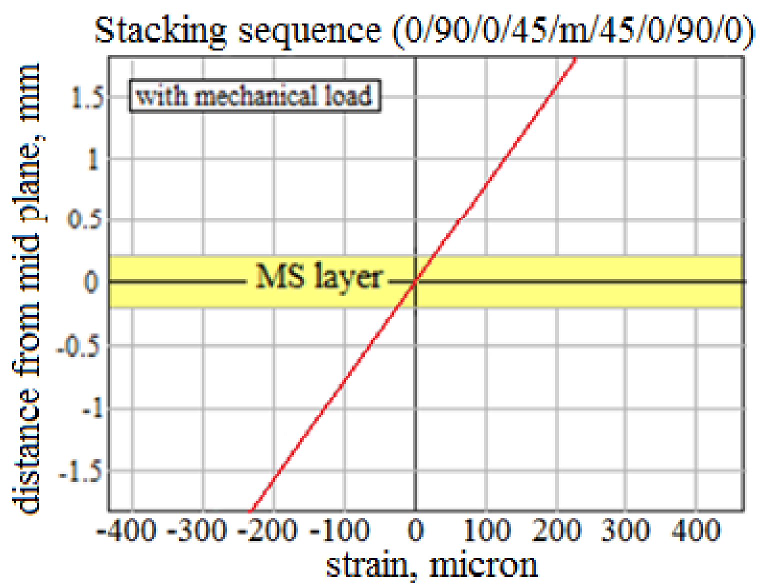


Symmetric laminate

Results…

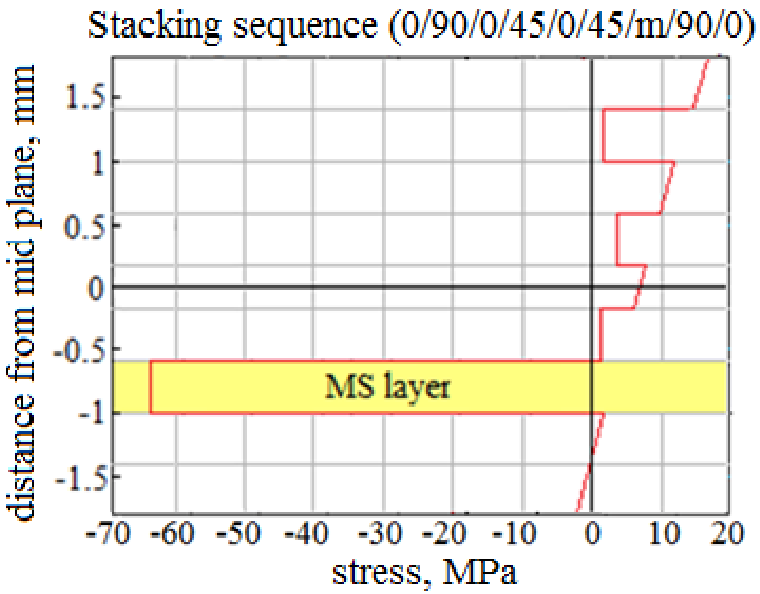
Stress and Strain variation s at various interfaces and in MS layer (mechanical load along with actuator current)

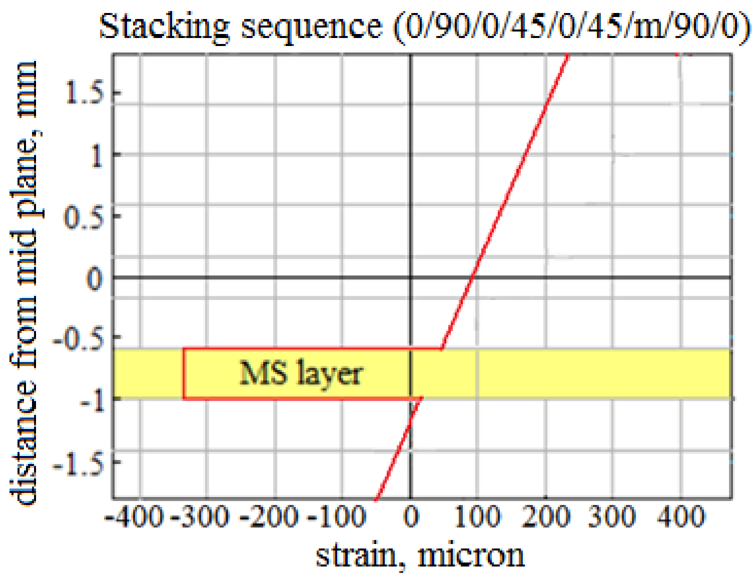




Symmetric laminate

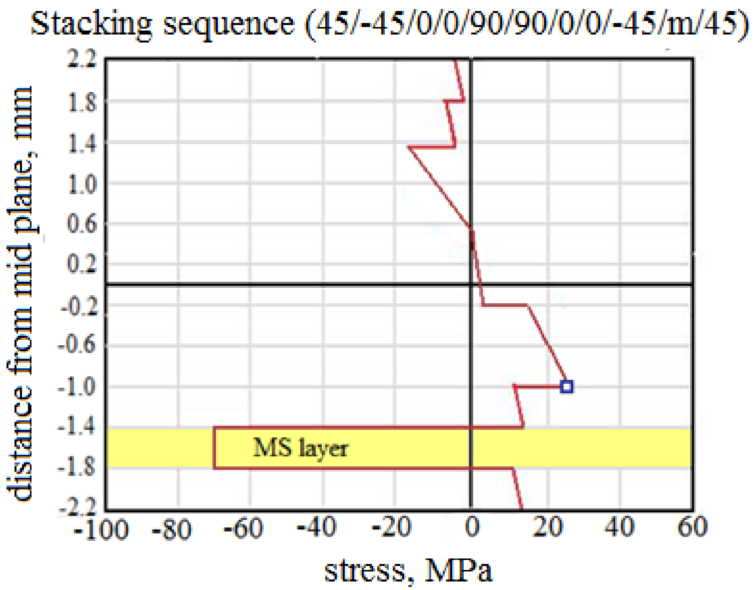
Stress and Strain variations at various interfaces and in MS layer (mechanical load along with actuator current)

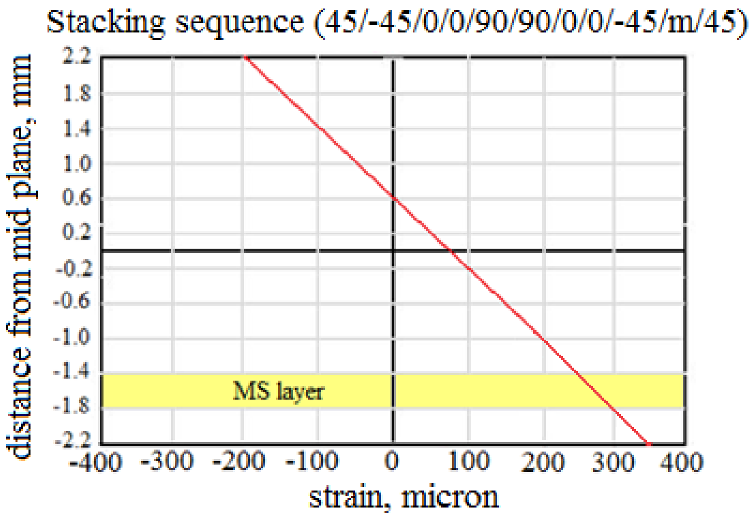




Assymmetric laminate

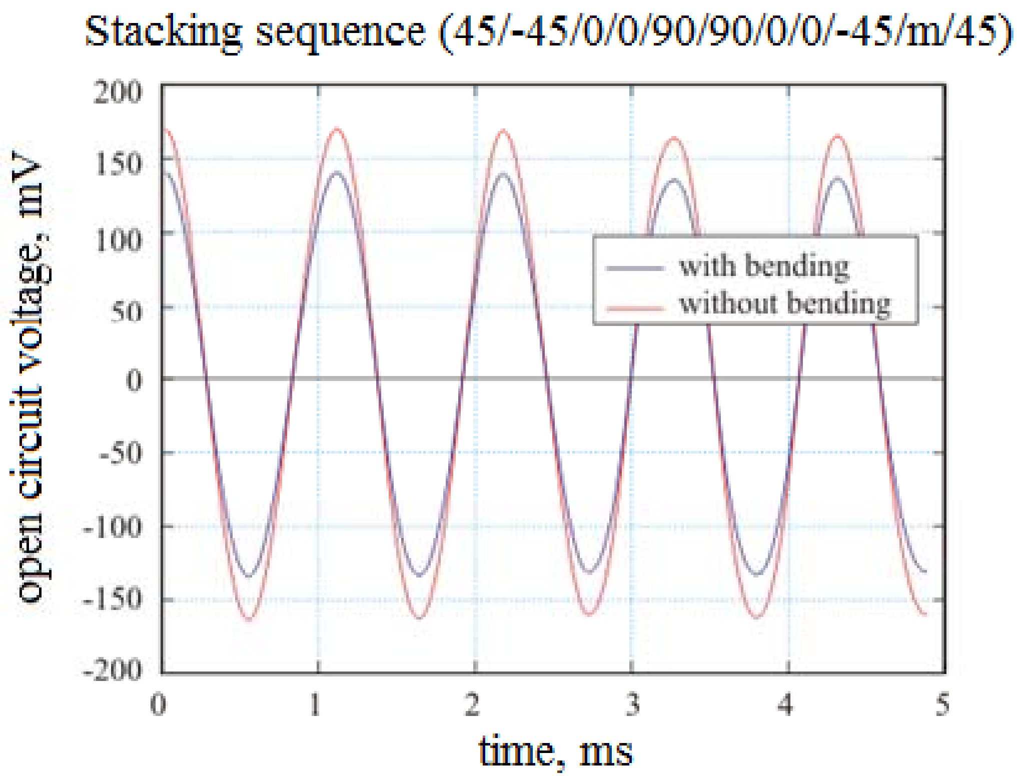
Stress and Strain variations at various interfaces and in MS layer (actuator current only)





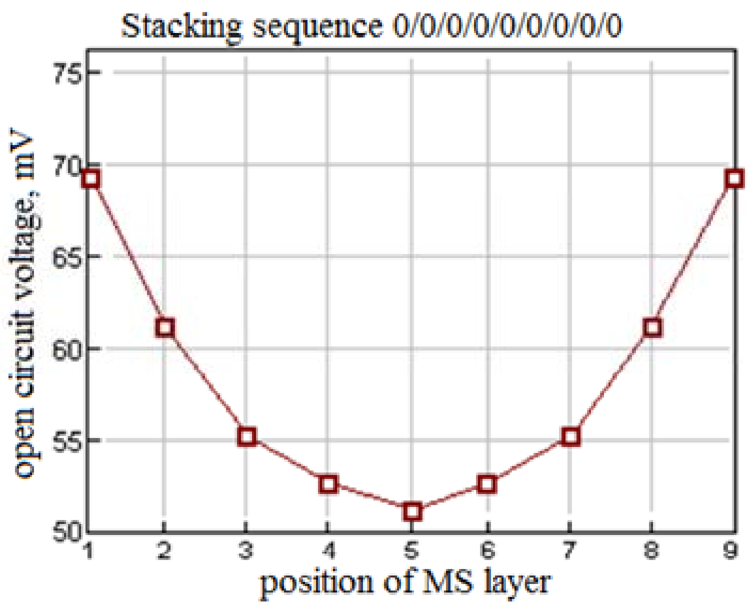
Assymmetric laminate

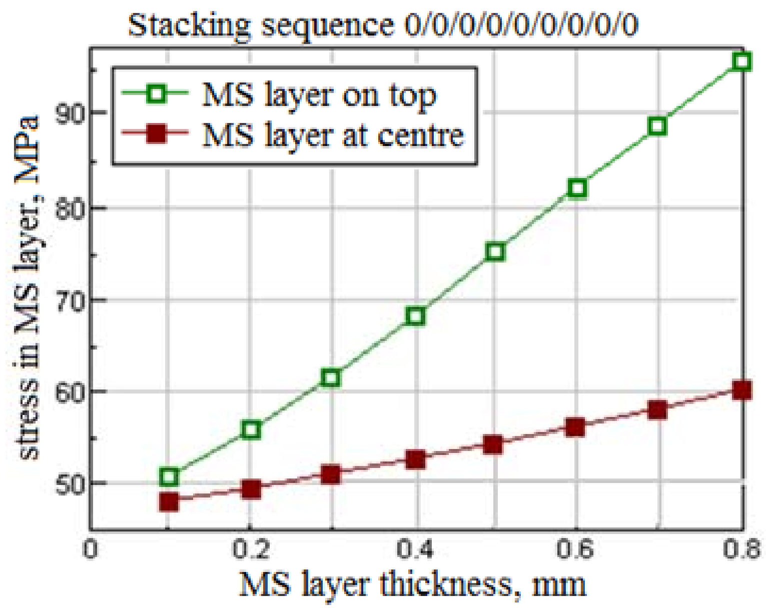
Open circuit voltage in MS layer at the time of delamination



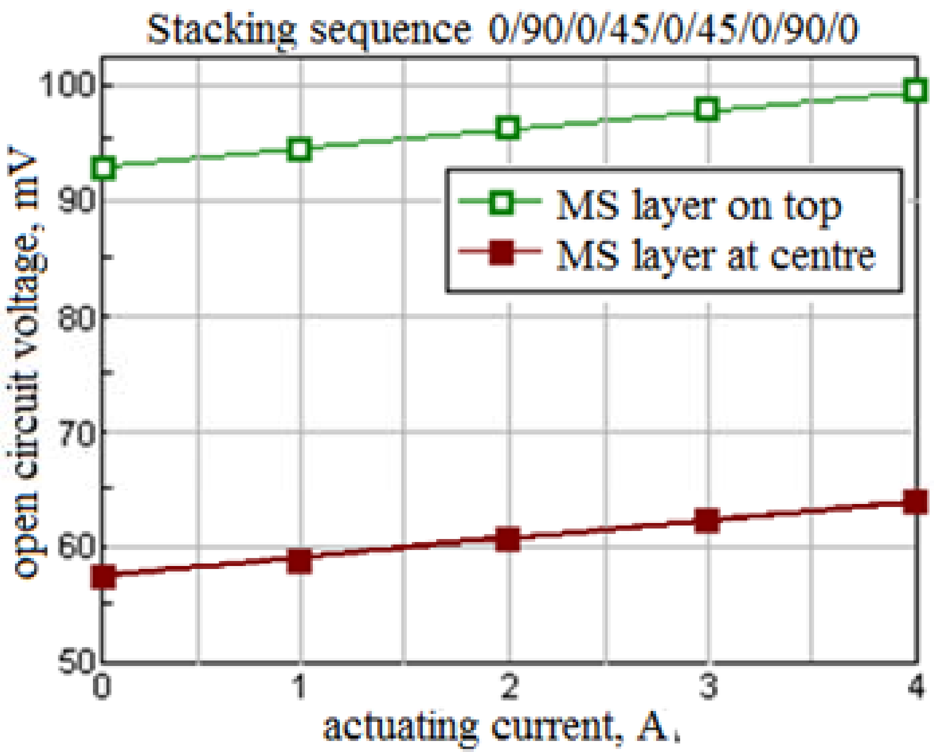
with and without bending consideration

Effect of position of MS layer amd its thickness

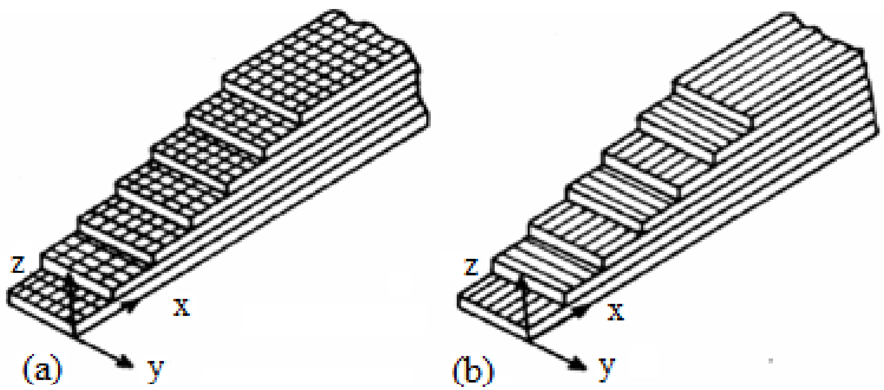




Open circuit voltage in the sensing coil with the increase in current in actuating coil.

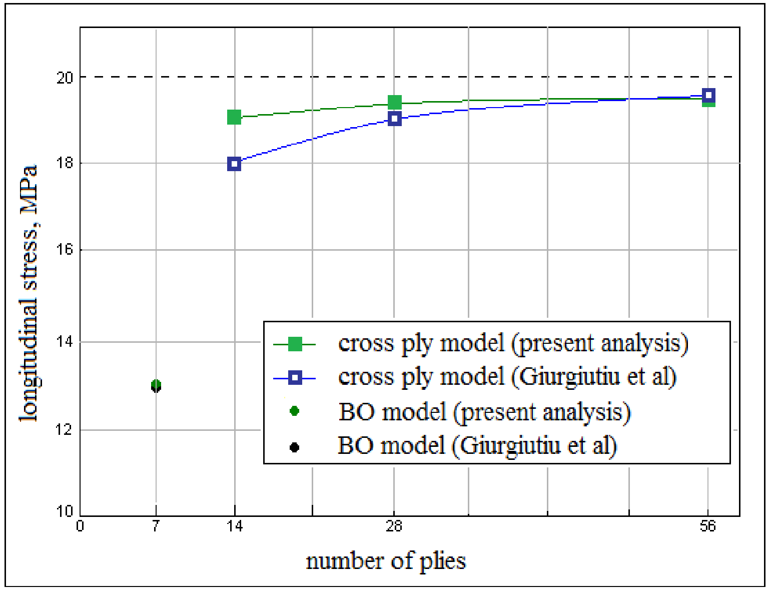


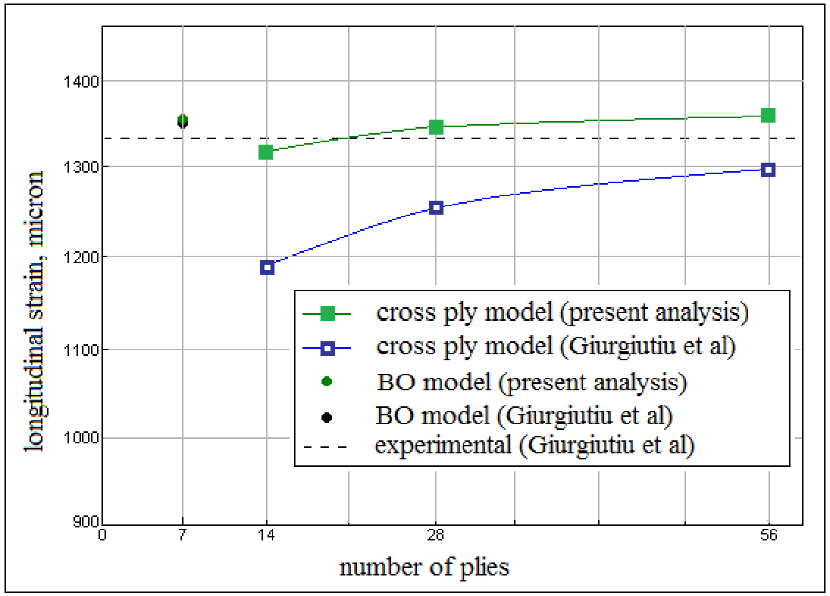
Validation of present model for woven composite



(a) Balanced orthotropic and (b) Orthotropic cross ply layup models.

Convergence of longitudinal stress and strain results on the beam surface under maximum load condition as predicted by various models





Major observations

- Variation of stress in delaminating interface and MS layer induces voltage in MS layer.
- Under axial loading, MS layer is subjected to compressive stresses while the remaining layers are under tension.
- In symmetrical laminates more than one interface can delaminate.
- MS layer thickness and location of the layer has a bearing on sensing voltage
- Effect of orientation of laminae is more prominent than bending effect.

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