Characterization of dynamic response of composite plates with embedded FBG sensors

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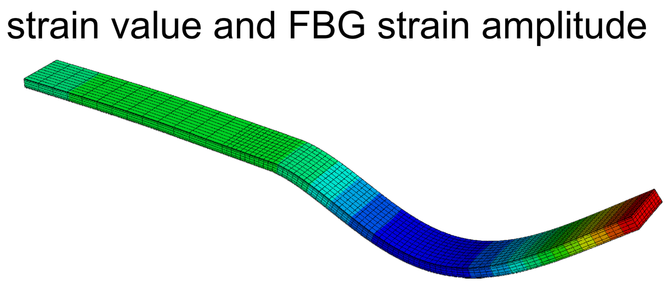
Objective

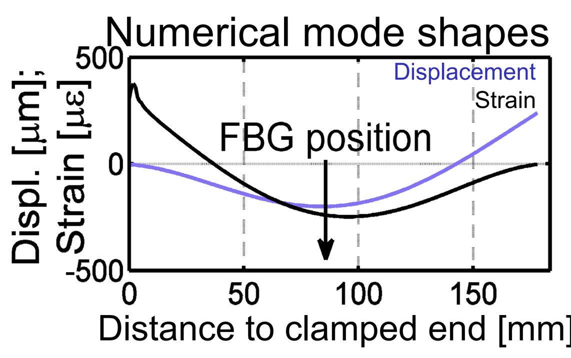
The present project is dedicated to the characterization of strain acquisition at rates up to 500 kHz via fiber Bragg grating (FBG) as strain sensor in composite materials under dynamic excitation.

Steady-state harmonic load

Numerical

- FE numerical modal analysis
- Output: Normalized displacement shapes and strain shapes along the central axis of the beam
- Comparison between experimental and numerical mode shapes using the modal assurance criterion (MAC)
- Comparison between numerical local strain value and FBG strain amplitude

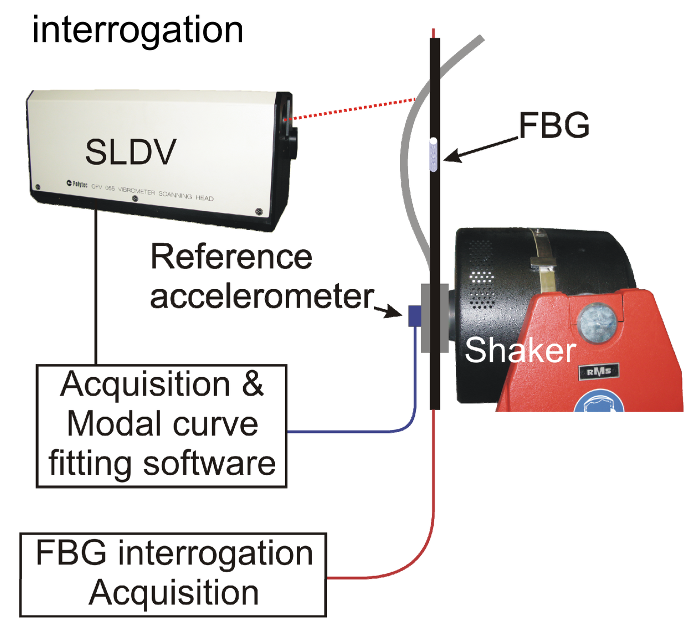




Numerical local strain value ↔ FBG strain amplitude

Experimental

- Test configuration: The CFRP UD beam is clamped on one end on an electrodynamic shaker
- Loading: Harmonic excitation at eigenfrequencies of bending modes
- Testing parameter: Length of the beam for a large frequency range
- Acquisition: Displacement shapes along central axis and FBG sensor interrogation



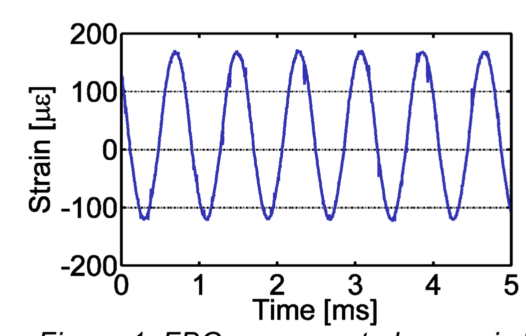
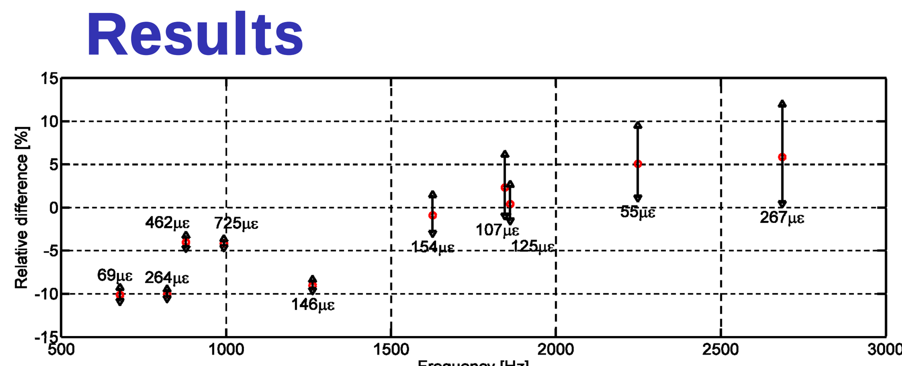


Figure 1: FBG response to harmonic load

Results

FE model validation

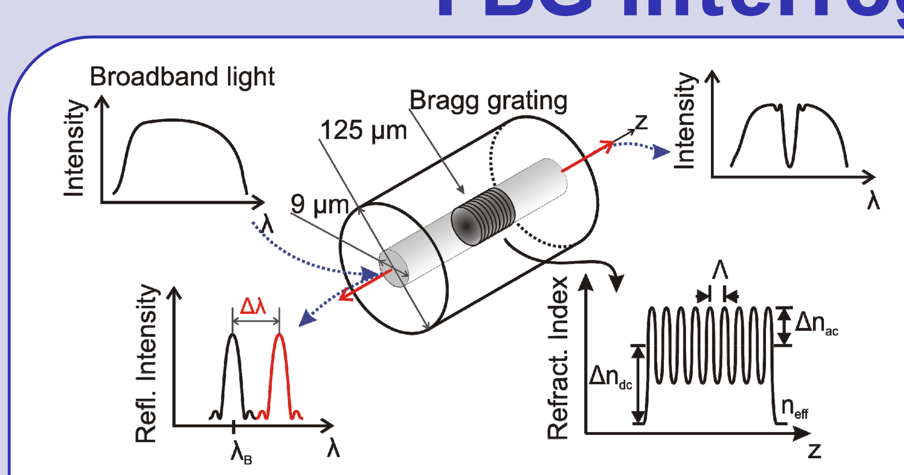
Good agreement between experimental and numerical mode shapes:
MAC ≥ 99.98 %



FBG strain data validation

Relative difference $\Delta = \frac{|\varepsilon_{FE} - \varepsilon_{FBG}|}{\varepsilon_{FE}}$ is between +/-10 % over a strain range of 800 µε and a frequency range of 3000 Hz. An uncertainty in position of the FBG of +/- 1 mm is evaluated.

FBG interrogation

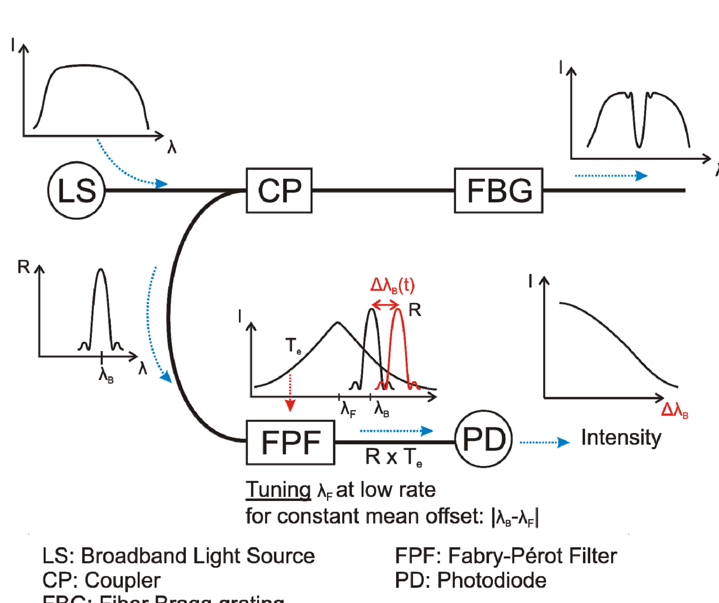


Bragg shift $\Delta\lambda_B$ due to three-dimensional strain state (ε_x, ε_y, ε_z)

$$\frac{\Delta\lambda_{Bx,y}}{\lambda_B} = \varepsilon_z - \frac{n_0^2}{2}\left[p_{11}\varepsilon_{x,y} + p_{12}(\varepsilon_z + \varepsilon_{y,x})\right]$$

where the Bragg wavelength λ_B is the central wavelength of the reflected peak.

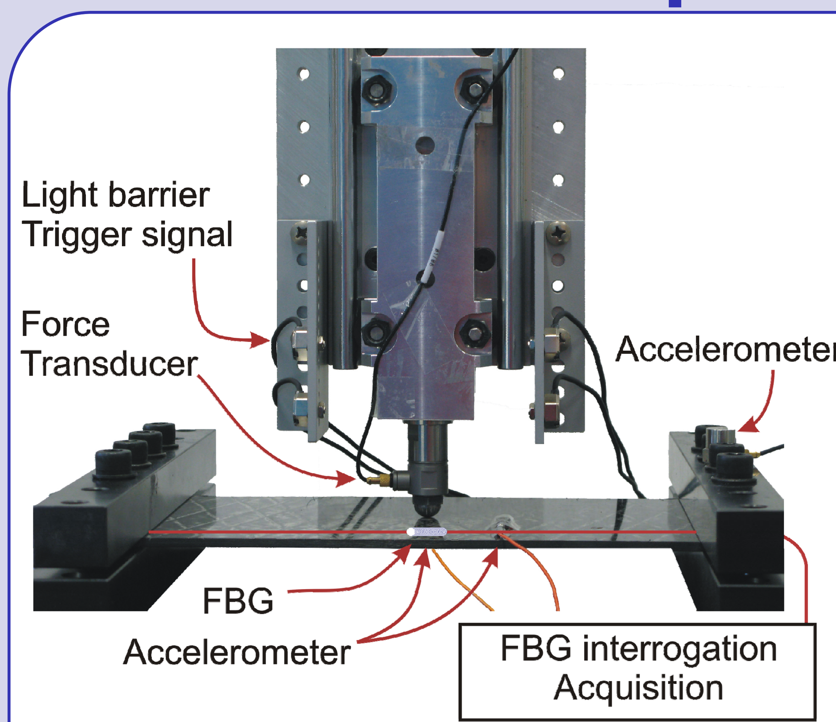
- Broadband light is coupled into the FBG.
- The reflection spectrum from the FBG is passed through a Fabry-Pérot (FP) tunable filter.
- The FP filter wavelength λ_F is tuned at low rate to be at a constant mean offset from the Bragg wavelength: $\int(\lambda_B - \lambda_F)dt = cst$
- A Bragg wavelength shift $\Delta\lambda_B(t)$ at high rate is modulated into an intensity variation I(t).
- Considering the filter function of the FP filter, the wavelength shift $\Delta\lambda_B(t)$ can be calculated.



Methodology

- CFRP plate processing using standard curing cycle in autoclave
- Determination of embedded fiber Bragg grating (FBG) position using OLCR
- Material properties identification using inverse mixed numerical experimental identification
- Experimental modal analysis of clamped specimens for numerical model validation
- Dynamic excitation of specimens using steady-state harmonic load and impact load
- Local strain measurements using embedded FBG and high rate interrogation system at 500 kHz
- Construction of validated FE model to obtain mode shapes of harmonically loaded beam and perform plate impact simulation
- Comparison of experimental and numerical local strain signals

Impact load

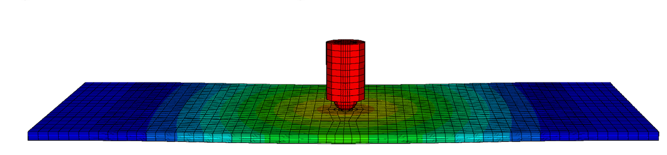


Experimental

- Test configuration: The CFRP cross-ply plate is clamped on both sides.
- Experimental modal analysis of clamped plate
- Loading: Impact load using a falling mass of weight 880 g
- Acquisition: Force and acceleration acquisition and FBG sensor interrogation triggered by common light barrier signal

Numerical

- FE impact simulation using explicit solver
- Parameters: Rayleigh damping coefficients fitted on experimentally determined modal damping ratios
- Output: Contact force and local acceleration for model validation and local strain field
- Comparison between numerical local strain signal and FBG signal



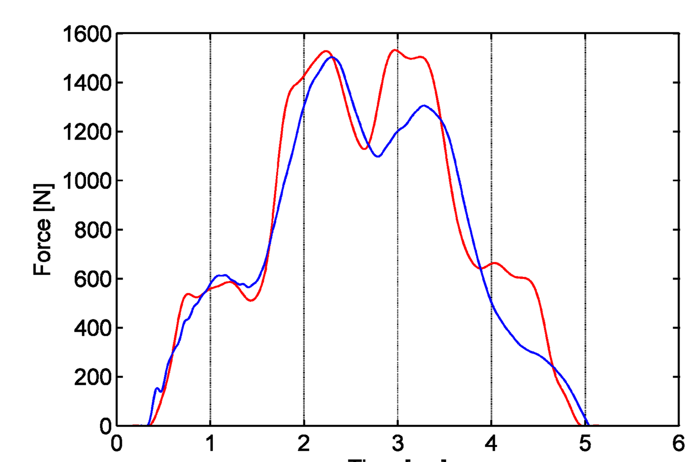


Figure 2: Comparison between experimental and numerical contact force for an impact energy of 2.6 J.

Results

- The repeatability of the FBG interrogation has been successfully proven for different impact energies.
- It has been shown that the experimental results coincide with the numerical data.
- The frequencies of the transient response of the plate can be identified and correspond to the eigenfrequencies determined by experimental modal analysis.

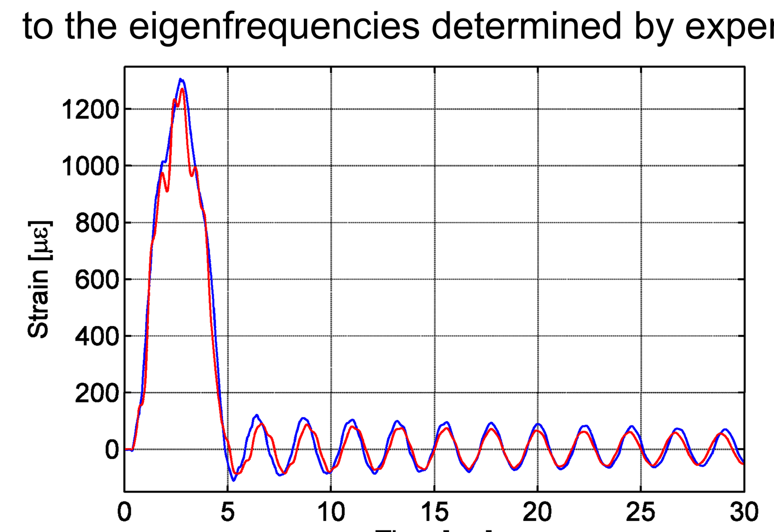


Figure 3: Comparison between experimental and numerical strain response to an impact load of 2.6 J.

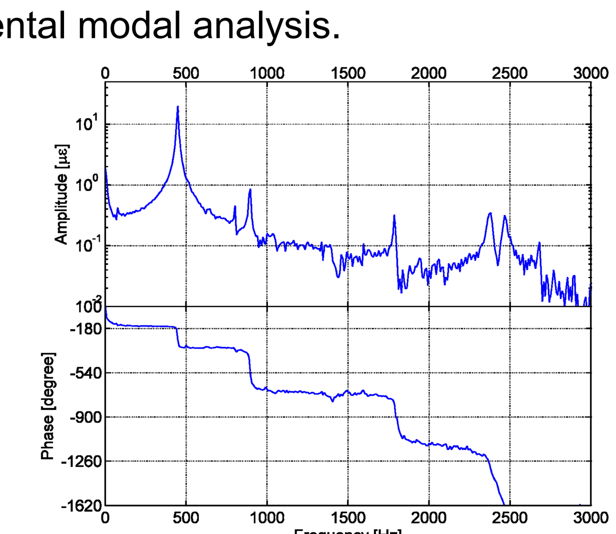


Figure 4: Spectrum of FBG transient strain response.

Conclusion

Embedded FBG sensors accurately measure the strain at selected locations. Such sensors are suited for dynamic strain sensing applications and pave the way for developing semi-experimental methods for structural monitoring, damage detection and control.

Thanks are due to the SNSF, Grant N°116715