

Monitoring thermally induced structural response modifications in a composite material oil pan

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Content

- Composite plastic materials and linear structural dynamics
- Modal models and poles'frequency shift due to temperature
- Detecting structural changes

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Introduction

- Modal model-based SHM of complex structures
 - Limitations of extracting modal models from modal test data
 - Influence of boundary conditions
 - Linear dynamic behavior only in limited operating field
- Ex: engine components made of composite plastic materials
- Modal tests on an engine oil pan at different temperatures
- Extending the applicability of a damage detection algorithm
- Working with FRF's
 - Detecting modal deviations due to operating conditions

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Composite plastic materials and linear dynamics

- Oil pan of a heavy-duty truck engine
 - PA66 polymer: polyamide of nylon 66 with a mat of 30% chunked glass fibers randomly distributed, ideally isotropic
 - Preferential directions for the fibers distribution
 - non-linear behavior
 - Operating at -20°C to 80°C → material properties vary
 - non-linear behavior
- Modal testing with varying temperatures and excitation levels

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Oil pan experimental set-up

- Standard dynamic test in free-free conditions
50-lb (peak force) electrodynamic shaker
- Accelerometers uniformly distributed over the surface
Sensitivity 100 mV/g, operating thermal range -54 to +121°C
- Artificial excitation: frequency range 10-400 Hz
flat multi-sine spectrum with random phases
- Oil pan filled with water
- Heat control system, water temperature from 8 to 70°C
- Six tests runs at 8, 20, 33, 45, 58 and 70 °C
- "White" tests
(plugs, seal, screws, oil ducts, thermocouple removed)

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Heating system



Cooling system

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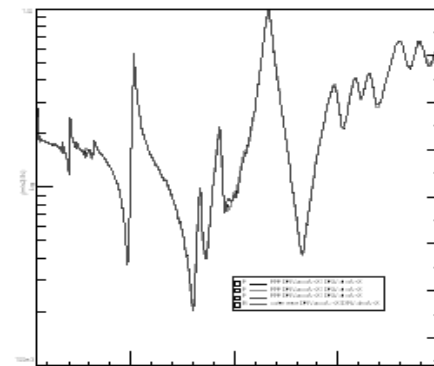
Composite plastic materials and linear dynamics (Contd.)

Linearity check

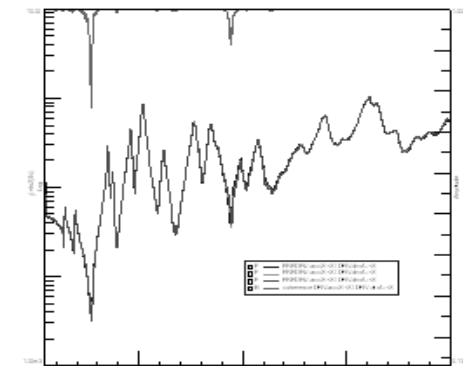
- Performed with increasing excitation levels
 - at ambient temperature: oil pan empty, filled with water
 - at each operating temperature
- Measuring responses at the driving point
- All FRF's for the different excitation levels overlap very well
 - linear behavior in the temperature range

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Linearity checks at ambient temperature



Empty oil pan

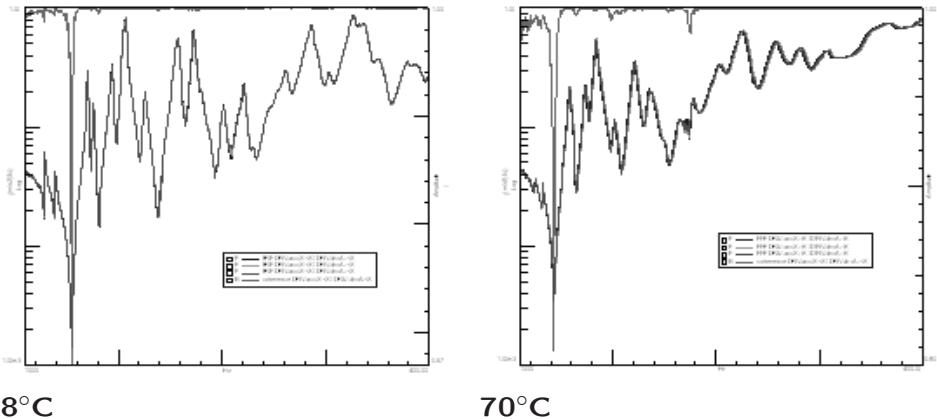


Water filled in oil pan

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Modal models and poles'frequency shift

Linearity checks at increasing temperatures



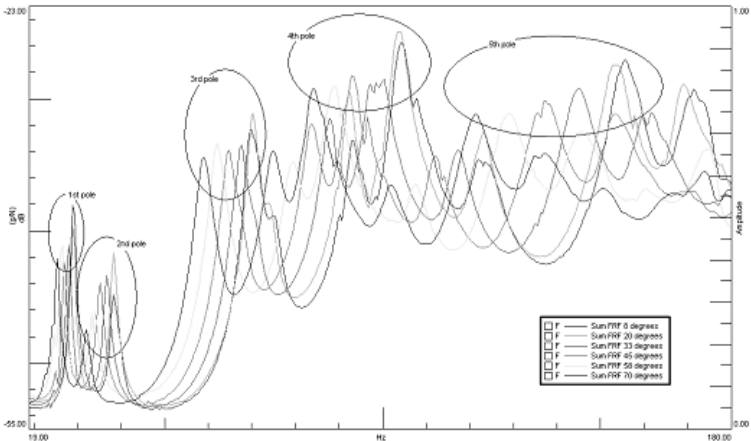
- At each operating temperature: modal models extracted using PolyMAX algorithm
- A frequency shift on each system pole
Eigenfrequencies decrease with the temperature increase
Larger frequency shifts for system poles at higher frequency

Explanation: $f = \sqrt{k/m}$, $m = \rho V$,
Elasticity modulus E stable up to 20°C,
linear decay until 80°C (half value), then stable

- Water absorption capacity → slight increase in dimensions and volume

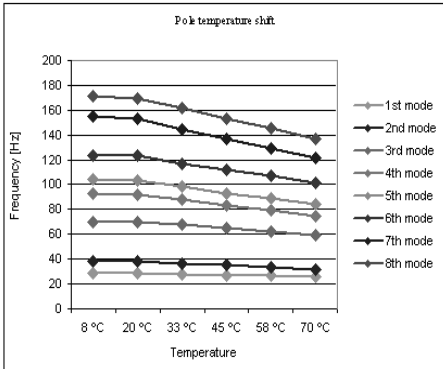
Thermal expansion → density decrease

Modal models and poles'frequency shift (Contd.)

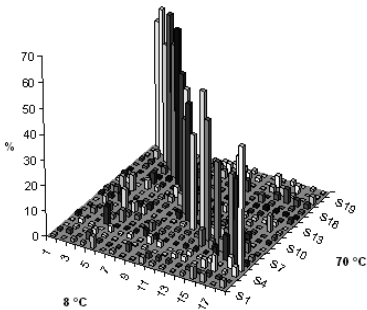


System poles for varying temperatures and corresponding frequency shift

Modal models and poles'frequency shift (Contd.)



Mode shapes frequency shift induced by temperature variations



MAC matrix (8°C and 70°C)

Different modal models for the same safe structure

Detecting structural changes

- Reference data → covariances → Hankel matrix \mathcal{H}_0

Left null space S s.t. $S^T \mathcal{H}_0 = 0$

- Fresh data → covariances → Hankel matrix \mathcal{H}_1

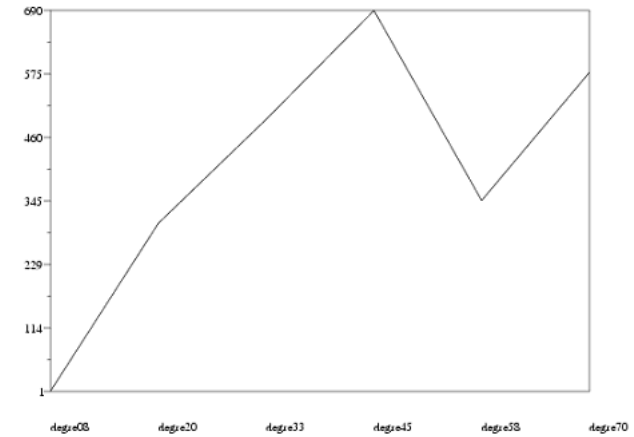
Check if $\zeta \triangleq S^T \mathcal{H}_1 \neq 0$

ζ asympt. Gaussian, test: χ^2 in ζ

- **New:** Hankel matrices filled with IRF
- Monitoring thermally induced structural changes

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Detecting structural changes (Contd.)

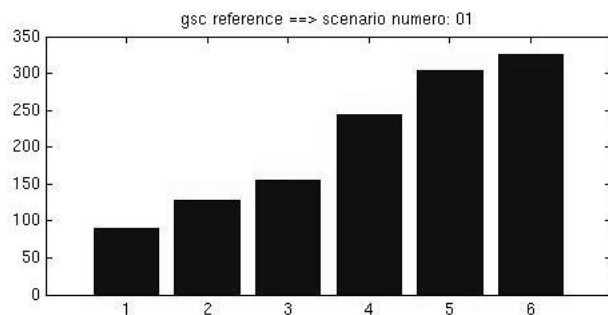


Test values for increasing temperatures

No theoretical evidence that the test value should increase with the change magnitude

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Detecting structural changes (Contd.)



Bridge deck - Test values for increasing temperatures
(constant spatial gradient)

Test values averaged over repeated experiments

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Conclusion

- Modal model-based approach to SHM
- Monitoring an engine oil pan made of composite plastic material with large temperature variations
- Temperature dependent structural modifications reliably reproduced in laboratory conditions
- (Non)linearities and frequency shifts addressed
- Temperature induced structural modifications detected
- Currently: Test damage scenario
Discriminate structural damage from thermal variations

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