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

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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

Content

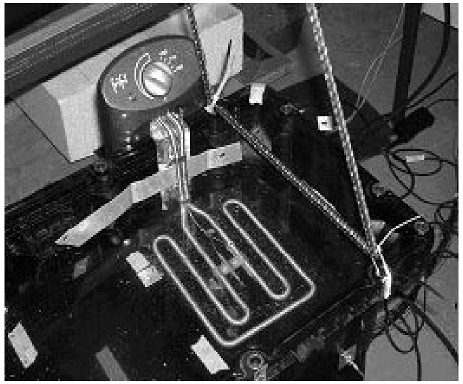
- Composite plastic materials and linear structural dynamics
- Modal models and poles'frequency shift due to temperature
- Detecting structural changes

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

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)



Heating system

Cooling system

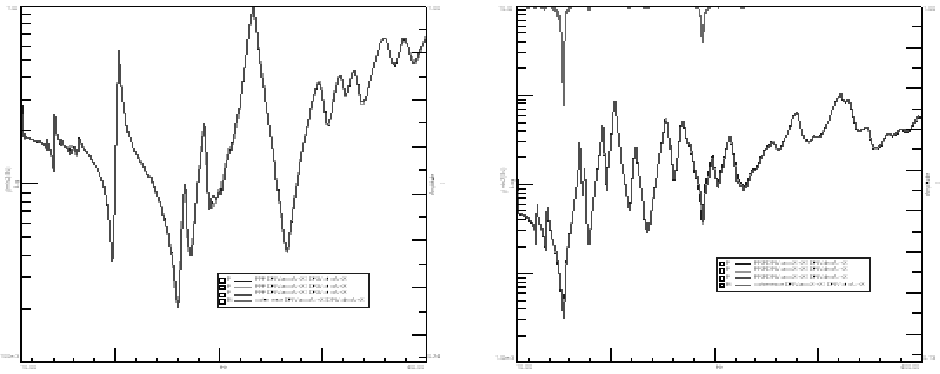
Composite plastic materials and linear dynamics (Contd.)

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

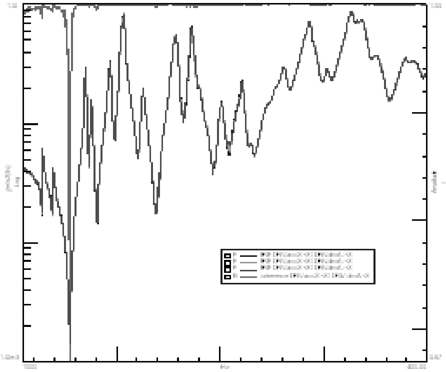
Linearity checks at ambient temperature



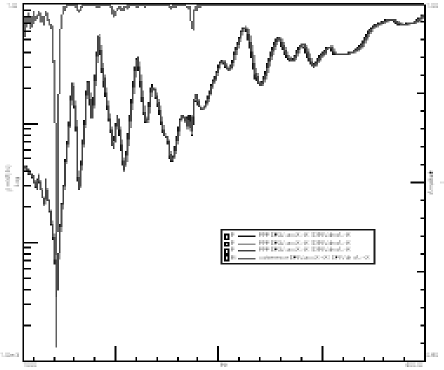
Empty oil pan

Water filled in oil pan

Linearity checks at increasing temperatures



8°C



70°C

Modal models and poles’frequency shift

- 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

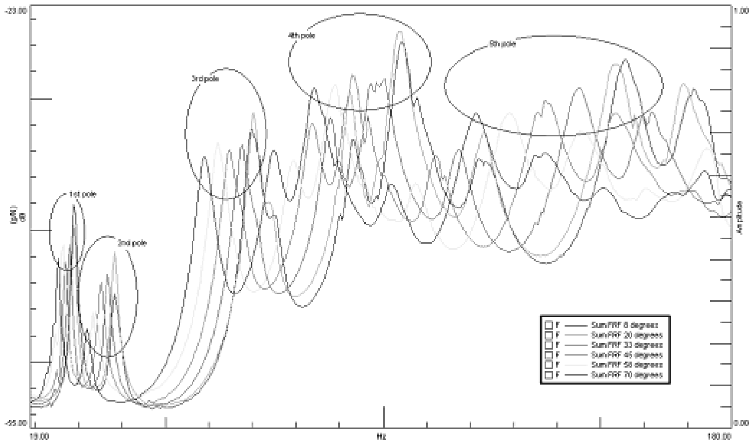
- Explanation: $f = \sqrt{k/m}, \quad m = \rho V,$

  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

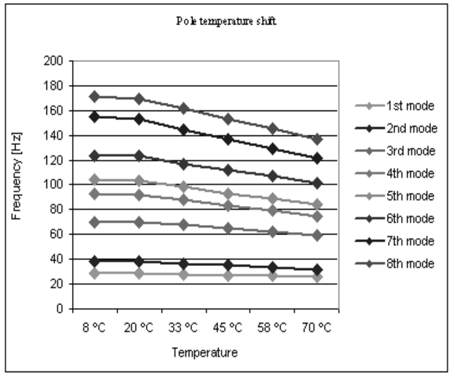
  Thermal expansion → density decrease

Modal models and poles’frequency shift (Contd.)

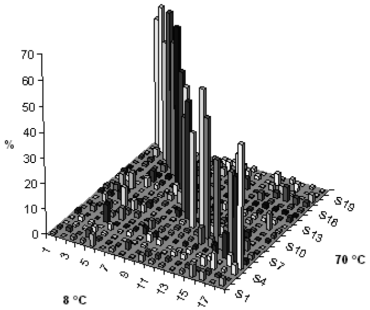


System poles for varying temperatures
and corresponding frequency shift

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 $\mathcal{H}_1$

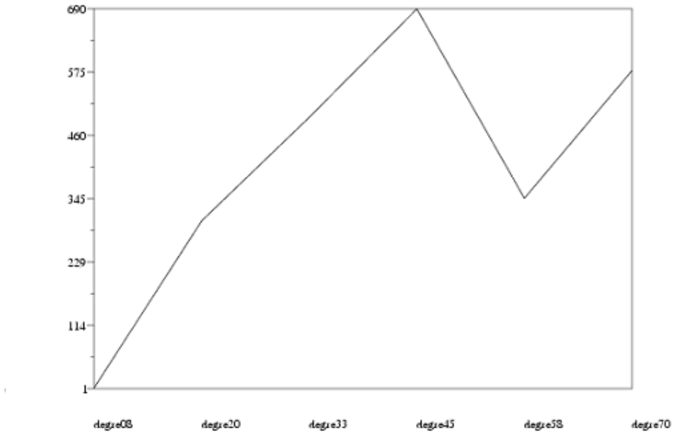
  Check if $\zeta \triangleq S^T\ \mathcal{H}_1 \neq 0$

  ζ asympt. Gaussian, test: χ^2 in ζ

- New: Hankel matrices filled with IRF

- Monitoring thermally induced structural changes

Detecting structural changes (Contd.)



Test values for increasing temperatures

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

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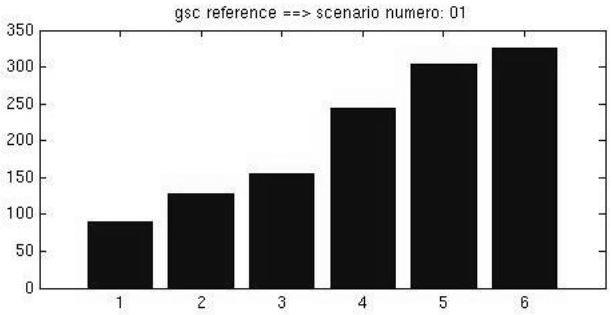
Detecting structural changes (Contd.)



Bridge deck - Test values for increasing temperatures
(constant spatial gradient)
Test values averaged over repeated experiments

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