SICODYN : benchmark pour l’évaluation du calcul dynamique et du recalage sur une structure industrielle

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Outline

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   - Objectives
   - What type of demonstrator?
   - Methodology

2. Total variability of numerical predictions in blind conditions
   - Modal characteristics on pump components

3. Parametrical study on boundary conditions

4. Measurement uncertainty
   - 2 identical modal analyses on a pump component
   - Modal analyses on the pump assembly with different boundary conditions

5. Numerical-experimental correlation
   - Modal characteristics on a pump component
   - Modal characteristics on pump assembly
   - Example of updating results

6. Conclusion – Further works
1. SICODYN benchmark definition

Benchmark objectives

- Quantify the credibility of numerical predictions in structure dynamics

- Observe the total variability of numerical predictions in blind conditions
- Measure the robustness to variability, uncertainty and lack of knowledge
- Quantify the measurement uncertainty
- Measure the fidelity of numerical predictions to test data
- Measure the improvement of numerical models using experimental data

- Duration: years 2008 to 2010
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What sort of demonstrator?

- Academical test ➔ NO
  - No experimental measurements, but a validation environment represented by the variation of input parameters
  - Ex: The Validation Challenge Workshop, 22-23 May 2006, Albuquerque, New Mexico
  - Organised by Sandia National Laboratories

- Laboratory device ➔ NO
  - Simplification of an industrial structure regarding the geometry, the physical and the environmental complexity
  - Ex: SMART CEA-EDF benchmark

- Industrial structure with fixed common parameters ➔ NO
  - Common material characteristics, boundary conditions,…

- Industrial structure in real simulation context
  - A typical industrial study with some unknown input data
  - Basic assumption: linear behaviour
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Target structure

Characteristics

- Industrial (or quasi) complex structure
- Assembly of several sub-structures (bolted, riveted…)
- Considered in its environment
- Excitation possibly unknown

Constraints

- Availability of plans or computer-aided designed, autorisation to disclose them to participants
- Possibility to measure in stationary or in operating conditions
- Possibility to partially dismount and reassembly the structure
- Limited time to elaborate the finite element model
1. SICODYN benchmark definition

The chosen demonstrator

The SULZER one-stage horizontal Booster pump

The CAD model pump assembly
1. SICODYN benchmark definition

EDF’s interest

- Until now: EDF demanded pump manufacturers to ensure that shaft critical speeds are not near the nominal rotating speed → simulations only relative to the shaft dynamic behaviour
- New item in EDF technical specifications for pumps:
  - For certain types of pumps, statoric part resonances too must not be near the rotating frequency → simulations not usual
- Consequence: EDF and manufacturers must get confident pump models
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List of partners (16)

- INSA Lyon
- FEMTO Besançon
- CETIM Senlis
- PHIMECA Engineering
- SAMTECH
- VIBRATEC
- EDF R&D
- (SULZER Pumps France)
- ILM Technology
- Ecole Polytechnique de Lausanne (Switzerland)
- Bristol University (United Kingdom)
- Politecnico di Milano (Italy)
- Gologanu (Roumania)
- MSO Industrial (Colombia)
- PIKITAN (Spain)
- CAEnable (USA)
- Delft University (The Netherlands)
1. SICODYN benchmark definition

Hierarchical process

Geometrical / Physical complexity

- Free-free separate component
- Free-free pair of components
- Free-free assembled pump
- Non-connected pump fixed in concrete
- Pump fixed and connected to pipes and other pump
- Pump in operating conditions

Environmental complexity

Environ-mental com-plexity
The 8 main pump components

1. shaft
2. bearing casing
3. bearing support
4. cooling flange
5. pump casing
6. suction flange
7. elbow
8. frame
2. Total variability of numerical predictions in blind conditions

Variability of separate pump component eigenfrequencies

### Steel pump components

- **Mean frequency gap (%)**

<table>
<thead>
<tr>
<th>Mode number</th>
<th>Steel pump components</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
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<tr>
<td>5</td>
<td></td>
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<tr>
<td>7</td>
<td></td>
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<tr>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

- **2% variability on Young's modulus**
- **5% mean variability on eigenfrequency values**

### Cast iron pump components

- **Mean frequency gap (%)**

<table>
<thead>
<tr>
<th>Mode number</th>
<th>Cast iron pump components</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>3</td>
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<td>9</td>
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</tr>
</tbody>
</table>

- **20% variability on Young's modulus**
- **11% mean variability on eigenfrequency values**
3. Parametrical study on boundary conditions

Parametrical analysis on the clamped boundary condition

Configuration 1: frame completely fixed in concrete
Configuration 2: frame partially fixed in concrete

![Graph showing frequency shift for different modes.](image-url)
Representation of connections between pump components

Bolted assembly: rigid connections via rigid relationships, elements or stucked surfaces

Ball and hydrodynamic bearings: estimated radial and axial stiffnesses
4. Measurement uncertainty

Focus on: variability between two measurements

Example: pump casing
- One modal analysis in 2009, the other one in 2010 at Sulzer Service in Velaux (Marseille)
- Same methods and means of measurements
- Two operators and two different structures

Outstanding conclusions
- Ability to pair modes from each experiment
- Frequency shift: max 3%
- BUT: maximum MAC between pairs is lower than 60%
4. Measurement uncertainty

**Focus on: pump connected to pipes**

- Modal analysis is more difficult to do
  - Modal sum:

- Correlation is OK for first mode
  - But more difficult on other shapes
5. Numerical-experimental correlation

Experimental-numerical comparison of separate component modal analyses: the pump casing example
5. Numerical-experimental correlation

Bearing support

3rd experimental mode missing
Experimental values between min-max numerical values
## 5. Numerical-experimental correlation

### Pump assembly: numerical-experimental correlation

<table>
<thead>
<tr>
<th>Mode</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion around x axis</td>
<td>162 Hz, 194 Hz, 208 Hz, 62 Hz, 170 Hz</td>
</tr>
<tr>
<td>Flexion along x transversal axis</td>
<td>134 Hz, 178 Hz, 146 Hz, 92 Hz</td>
</tr>
<tr>
<td>Flexion along z longitudinal axis</td>
<td>77 Hz, 103 Hz, 111 Hz, 45 Hz, 90 Hz</td>
</tr>
<tr>
<td>Non identified mode</td>
<td>91 Hz, 109 Hz</td>
</tr>
<tr>
<td>Flexion of the pump casing</td>
<td>90 Hz, 45 Hz, 111 Hz, 103 Hz, 77 Hz</td>
</tr>
<tr>
<td>Flexion along z longitudinal axis</td>
<td>92 Hz, 146 Hz, 178 Hz, 134 Hz</td>
</tr>
<tr>
<td>Flexion along x transversal axis</td>
<td>170 Hz, 62 Hz, 208 Hz, 194 Hz, 162 Hz</td>
</tr>
<tr>
<td>Torsion around x axis</td>
<td></td>
</tr>
</tbody>
</table>
5. Numerical-experimental correlation

Example of updating results for the pump casing component

<table>
<thead>
<tr>
<th>Mode</th>
<th>initial</th>
<th>updated</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>-2.0</td>
<td>0.4</td>
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<tr>
<td>2</td>
<td>-2.8</td>
<td>-0.3</td>
</tr>
<tr>
<td>3</td>
<td>-11.3</td>
<td>-9.1</td>
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<tr>
<td>4</td>
<td>-0.6</td>
<td>1.9</td>
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<tr>
<td>5</td>
<td>0.0</td>
<td>2.5</td>
</tr>
<tr>
<td>6</td>
<td>-1.1</td>
<td>1.4</td>
</tr>
<tr>
<td>7</td>
<td>1.5</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Frequency error (%)

Young’s modulus: 2.0E+11 $\rightarrow$ 2.1E+11
Density: 7800 kg/m$^3$ unchanged
Poisson’s coefficient: 0.3 unchanged
Purpose for a comparative and updating process

- Compare numerical results
  - Participant 1
  - Participant 2
  - Participant n

- Compare experimental results
  - Measurement 1
  - Measurement 2

Numerical variability
- Conceptual modeling
- Mathematical modeling
- Model parameters, input data
- Discretisation
- Software, numerical methods

Experimental variability
- Measurement system
- Identification process
- Realisation (identical structures, systems modified after a partial dismount/reassembly)

Compare numerical-experimental results

Fidelity to test data
6. Conclusion

Conclusion on reliability on modal models of sub-structures

- **Numerical aspects**
  - Narrow numerical variability on eigenmodes

- **Numerical-experimental correlation**
  - **Blind simulations**
    - Experimental eigenfrequency values are within the min.-max. numerical eigenfrequency value interval
    - Modeshape correlation not quite satisfactory (based on MAC criterion)
  - **Updated simulations**
    - Improvement of the eigenfrequency values, but MAC unchanged

- **Ability of numerical models to accurately predict the global modal behaviour of a complex structure**

- **Is the updating of the sub-structure model parameters necessary to increase the reliability of the built-up structure?**
Questions to be pointed out

- Can a purely blind numerical model accurately represent the dynamical behaviour of a built-up structure in its environment?
  - What are the relative parts of the modeling error and the parametrical error?
  - Can a parameter updating compensate the modeling error?
  - What parameter variations are acceptable, in order to obtain an admissible numerical model (i.e. which intercepts the experimental set of output data)?

- What are the minimal adequate experimental measurements necessary to obtain a confident model?
  - What necessary measurements, function of the final use of the numerical model?

- What modelisation points to first improve (connection representations, boundary conditions, sub-structure models)?