What’s on my LinkedIn page?

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Co-founder at VIBES.technology | looking for developers (C#/WPF)/
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2005 – 2011: BSc. / MSc. Engineering Dynamics @ TU Delft

2011 – 2016: PhD @ TU Delft (PME) / BMW Group

2016: Co-founder of start-up @ YES!Delft Incubator

VIBES.technology
VIBES’ team consists of Mechanical Engineers with extensive experience in sound and vibration Engineering and roots at Delft University of Technology.

VIBES assists companies across industries in sound and vibration R&D processes using technologies of Experimental Modelling, Dynamic Substructuring, Source Characterisation and Transfer Path Analysis.
NVH = noise, vibration and harshness: common abbreviation in automotive industry for the field of sound & vibration engineering.

**TRENDS & CHALLENGES in AUTOMOTIVE NVH:**
- Modular Design
- Product Diversification
- PHEVs / EVs
- Regulations
- Shorter time-to-market

**DRIVERS in NVH ENGINEERING**
- Sound signature (‘premium’, ‘sporty’)
- Wear and tear of components
- Quality Assessment

Examples of modularisation in automotive industry (top: Volvo, bottom: Renault)

COMMON MODULE FAMILY (CMF) : 4+1 BIG MODULES
Current design cycle: V-model with iterations

- Concept
- Design and Simulation
- Component Prototyping
- Test and Integration
- End Product

Iterative process with feedback loops.
Vision: first-time-right NVH engineering

‘First-time-right’ NVH engineering by integrating measurements and FEM in early-phase NVH simulations
WHAT DO WE NEED TO FULFIL THIS VISION?
‘First-time-right’ NVH engineering by integrating measurements and FEM in early-phase NVH simulations’

Modular calculations:
Dynamic Substructuring
The ability to simulate full system dynamics from its substructures, combining several modelling domains
Frequency Based Substructuring

High quality models:
Experimental Modelling
Creation of a ‘common interface’ by transforming a measurement to a FE-compatible model, with objective quality information
Virtual Point Transformation

Independent source description:
Source Characterization
Description of active source vibrations by an independent quantity, suitable for test bench measurements and target setting
Blocked Forces
SYSTEM MODELLING
Combine component models in a modular fashion using Dynamic Substructuring

COMPONENT “A”

Experiment Simulation Hybrid (SEMM)

COMPONENT “A” MODEL

Dynamic Substructuring

Excitation (blocked forces)

COMPONENT “B”

Experiment Simulation Hybrid (SEMM)

COMPONENT “B” MODEL

M, C, K

SYSTEM ASSEMBLY

NVH LEVELS
DYNAMIC SUBSTRUCTURING
Frequency based Substructuring – the Dual Assembly

\[ \mathbf{u} = \mathbf{Y}(\mathbf{f} + \mathbf{g}) \]
\[ \mathbf{g} = -\mathbf{B}^T \lambda \]

Equilibrium condition satisfied a priori

\[ \left\{ \begin{aligned}
\mathbf{u} &= \mathbf{Y}(\mathbf{f} - \mathbf{B}^T \lambda) \\
\mathbf{B} \mathbf{u} &= 0
\end{aligned} \right. \]

The system above can be solved by substituting the first line into the compatibility equation and solve for \( \lambda \):

\[ \mathbf{BY}(\mathbf{f} - \mathbf{B}^T \lambda) = 0 \]

\[ \mathbf{BY} \mathbf{f} = \mathbf{BYB}^T \lambda \]

\[ \lambda = \left( \mathbf{BYB}^T \right)^{-1} \mathbf{BY} \mathbf{f} \]

“Intensity of interface force to close the interface gap resulting from external forces”

The coupled response is obtained by substitution of the Lagrange multipliers into:

\[ \mathbf{u} = \mathbf{Y}(\mathbf{f} - \mathbf{B}^T \lambda) \]

\[ \mathbf{u} = \mathbf{Yf} - \mathbf{YB}^T \left( \mathbf{BYB}^T \right)^{-1} \mathbf{BYf} \]

The coupled response can be computed using substructure admittances.

Very useful as admittances can be measured!
EXPERIMENTAL MODELLING
THE VIRTUAL POINT TRANSFORMATION – Concept

How to obtain a dynamic model from measurements?

*with proper ‘FEM-like’ behaviour on the nodes?*

and quality checks on the substructure models?
EXPERIMENTAL MODELLING
THE VIRTUAL POINT TRANSFORMATION – Interface Displacement Modes (IDMs)

**n** measurements
i.e. accelerometer channels

6 virtual DoFs
 i.e. translations and rotations

**Remainder:**
(i.e. flexibility, noise)

**Reduction basis (IDMs)**
i.e. kinematic relation w.r.t. the virtual point

<table>
<thead>
<tr>
<th>rigid transformation:</th>
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| \[
\begin{bmatrix}
u^k_X \\
u^k_Y \\
u^k_Z \\
\end{bmatrix} =
\begin{bmatrix}
1 & 0 & 0 & 0 & r^k_Z & -r^k_Y \\
0 & 1 & 0 & -r^k_Z & 0 & r^k_X \\
0 & 0 & 1 & r^k_Y & -r^k_X & 0 \\
\end{bmatrix} q' +
\begin{bmatrix}
\mu^k_X \\
\mu^k_Y \\
\mu^k_Z \\
\end{bmatrix}
\] |

**u =** \( R_u q + \mu \rightarrow q = (R_u)^+ u \quad R_u \in \mathbb{R}^{n \times 6} \)

\begin{equation}
\mathbf{u} = \mathbf{Y} \mathbf{f} \\
\mathbf{q} = (R_u)^+ \mathbf{Y} (R_i^T)^+ \mathbf{m} \rightarrow \mathbf{q} = Y_{qm} \mathbf{m}
\end{equation}
Virtual Point Transformation:

- A structural dynamic model from measurements
- Obtain 6 DoFs per coupling point (Translations, Rotations)
- Couple virtual ‘node’ to Finite Element Model

EXPERIMENTAL MODELLING
THE VIRTUAL POINT TRANSFORMATION – Application on an E-drive (3 kHz)
The operational excitations are characterised by independent forces on the connection points of the structure on a dedicated test bench, in a three step approach:

1. Measure Structural Components
2. Operational measurements
3. Calculation of blocked forces

After the characterization of the active component with blocked forces, a validation on the test bench is carried out. This step provides insight in the quality of the procedure.

This validation is according to the methods proposed by ISO working group ISO/TC 43/SC 1/WG 57.

The forces on the coupling points of the e-compressor can be applied on the interface of the compressor and its connecting structure to predict the NVH-levels on a point of interest in the receiving structure.
EXPERIMENTAL DYNAMIC SUBSTRUCTURING
Potential of the technology in a nutshell

COMPONENT MODELLING
- Accurate model in the kHz range
- Compatible with FE (simulation)
- 80% time reduction for FE-calibration
- Opens new way of ‘FE-analysis’

SOURCE CHARACTERISATION
- Independent characterization on a test bench
  (no influence of the environment)
- Virtual acoustic prototyping!
  (fewer physical tests)
- Clear targets for OEMs and suppliers

SYSTEM MODELLING
- Modular approach
- Combine measurements with FE
- Efficient optimization of components
  (fewer physical prototypes required)
- Sharing between OEM/supplier