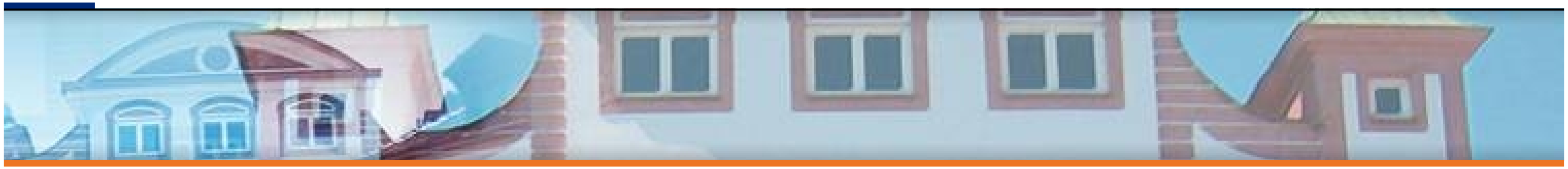
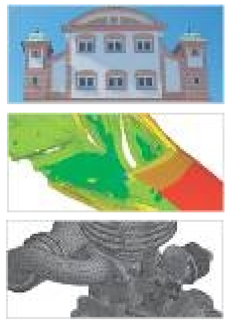


Efficient Simulation for Strongly Coupled Noise-Vibration-Harshness (NVH)

R. S. Puri, D. Morrey, Oxford Brooks
E. B. Rudnyi, CADFEM



CADFEM

Background

- Joint work 2004-
- Over email
- Available online
  - ModelReduction.com/contrib/Srinivasan.Puri/

Krylov Subspace Based Direct Projection Techniques for Low Frequency, Fully Coupled, Structural Acoustic Analysis and Optimization.

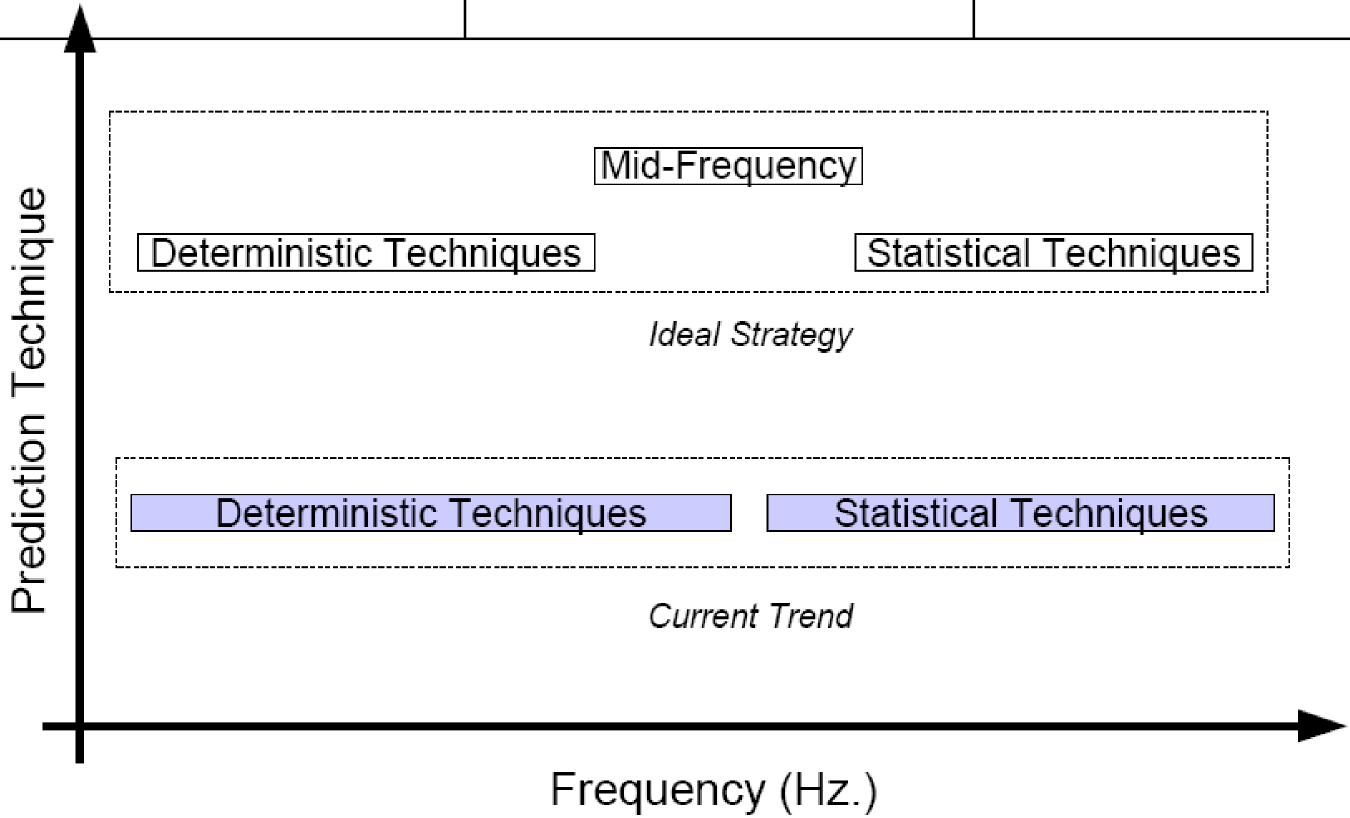
R. Srinivasan Puri

A thesis submitted in partial fulfillment of the requirements of Oxford Brookes University for the degree of Doctor of Philosophy.

13th March 2008

NVH Simulation

Low Frequency	Structure borne	0 – 100 Hz
Mid Frequency	Structure and air borne	100 – 250 Hz
High Frequency	Air born	> 250 Hz



Fully Coupled Finite Element Discretization

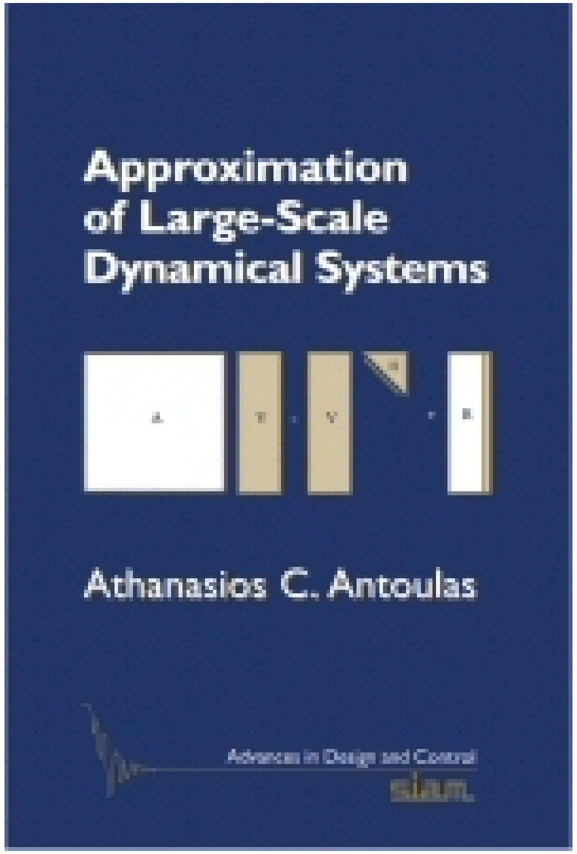
$$\left(-\omega^2\begin{bmatrix} M_s & 0 \\ M_{fs} & M_a \end{bmatrix} + j\omega\begin{bmatrix} C_s & 0 \\ 0 & C_a \end{bmatrix} + \begin{bmatrix} K_s & K_{fs} \\ 0 & K_a \end{bmatrix}\right)\begin{Bmatrix} u \\ p \end{Bmatrix} = \begin{Bmatrix} F_s \\ F_a \end{Bmatrix}$$

- FLUID29/FLUID30 in ANSYS
- The element size should be smaller than wavelength
  - High dimensional models
- Unsymmetric matrices

CADFEM

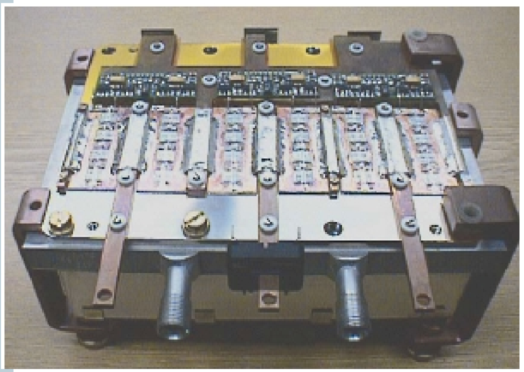
Model Order Reduction

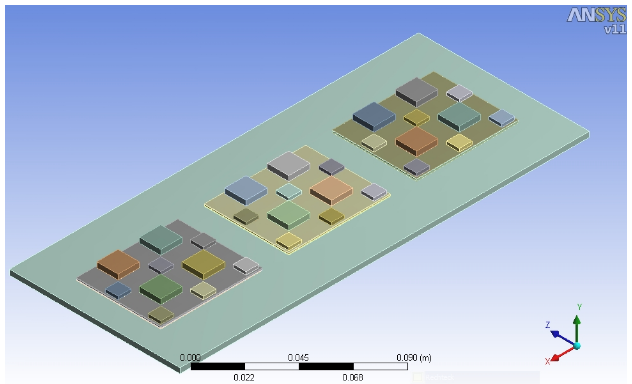
- Relatively new technology
- Solid mathematical background:
  - Approximation of large scale dynamic systems
- Dynamic simulation:
  - Harmonic or transient simulation
- Industry application level:
  - Linear dynamic systems only

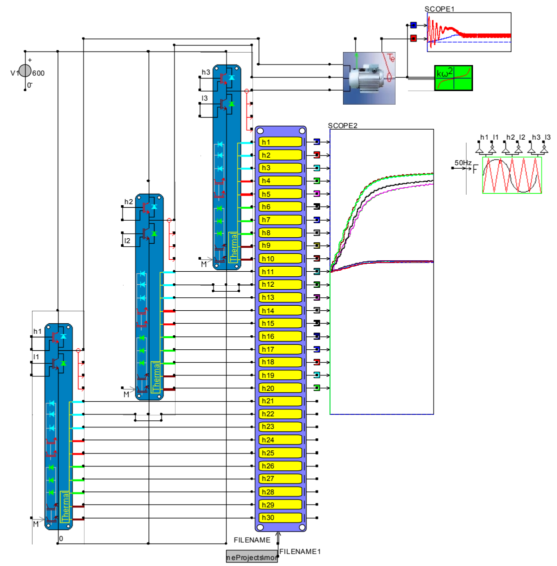


From Finite Elements to System Simulation

Physics & Geometry → **FEM** → System of n ODEs → **MOR** → Reduced System of $r << n$ ODEs





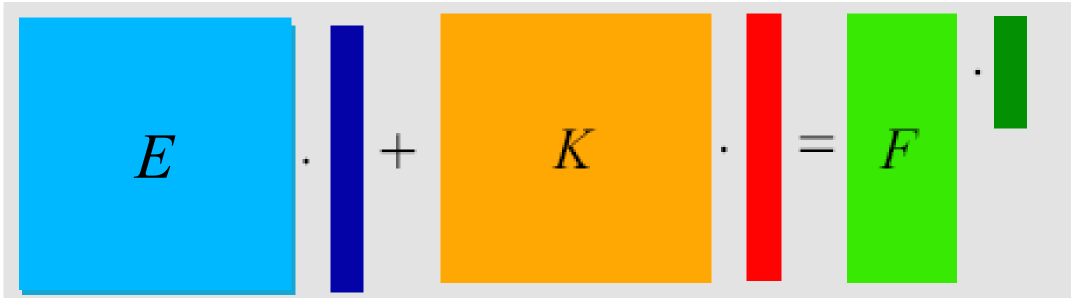


- Electrothermal Simulation with IGBTs:
  - From ANSYS Workbench to Caspoc (Eurosime 2008)

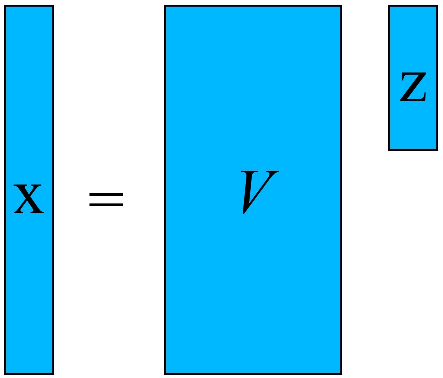
Model Reduction as Projection

- Projection onto low-dimensional subspace

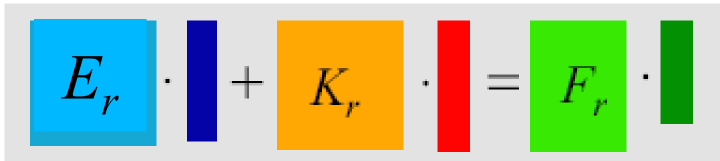
$$E\dot{\mathbf{x}} + K\mathbf{x} = B\mathbf{u}$$



$$\mathbf{x} = V\mathbf{z} + \varepsilon$$



$$V^T E V\dot{\mathbf{z}} + V^T K V\mathbf{z} = V^T B\mathbf{u}$$

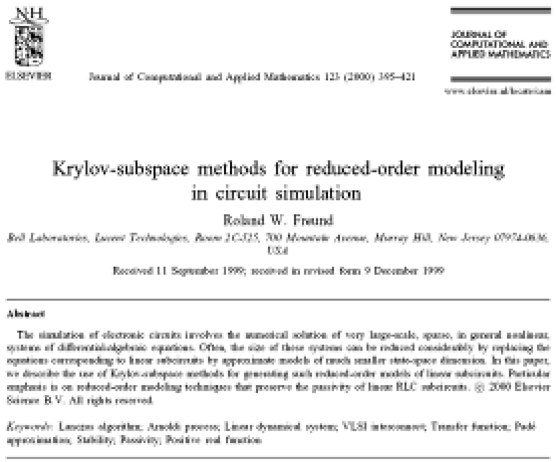


- How to find subspace?
- Mode superposition is not the best way to do it.

CADFEM

Implicit Moment Matching

- Padé approximation
- Matching first moments for the transfer function



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JOURNAL OF COMPUTATIONAL AND APPLIED MATHEMATICS

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Krylov-subspace methods for reduced-order modeling in circuit simulation

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Abstract

The simulation of electronic circuits involves the numerical solution of very large-scale, sparse, in general nonlinear, systems of differential-algebraic equations. Often, the size of these systems can be reduced considerably by replacing the equations corresponding to linear subcircuits by approximate models of much smaller state-space dimension. In this paper, we describe the use of Krylov-subspace methods for generating such reduced-order models of linear subcircuits. Particular emphasis is on reduced-order modeling techniques that preserve the passivity of linear RLC subcircuits. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Lanczos algorithm; Arnoldi process; Linear dynamical system; VLSI interconnect; Transfer function; Padé approximation; Stability; Passivity; Positive real function

- Implicit Moment Matching:
  - via Krylov Subspace

$$E\dot{\mathbf{x}} + K\mathbf{x} = B\mathbf{u}$$

$$H(s) = (sE + K)^{-1} B$$

$$H = \sum_0^{\infty} m_i (s - s_0)^i$$

$$H_{red} = \sum_0^{\infty} m_{i,red} (s - s_0)^i$$

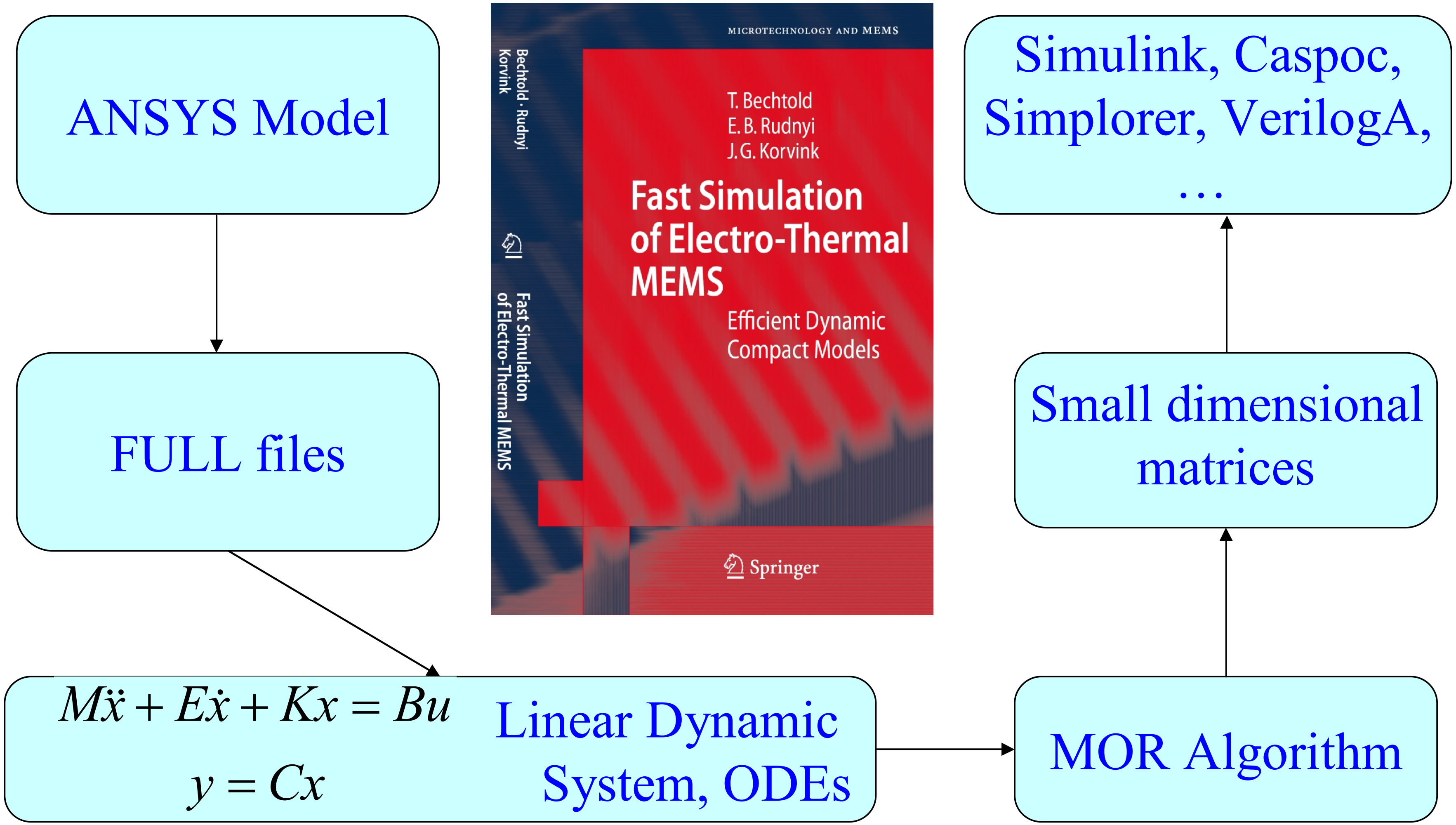
$$m_i = m_{i,red}, \quad i = 0, \ldots, r$$

$$s_0 = 0$$

$$V = span\{\Im(K^{-1}E, K^{-1}b)\}$$

CADFEM

MOR for ANSYS: http://ModelReduction.com

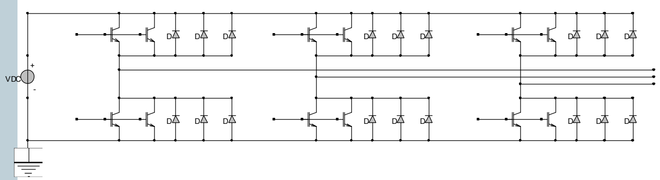


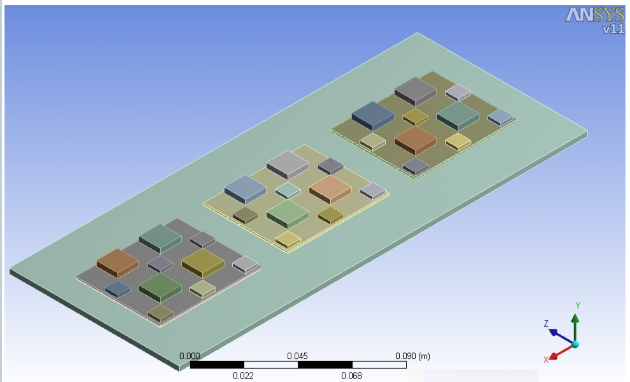
Current version 2.5

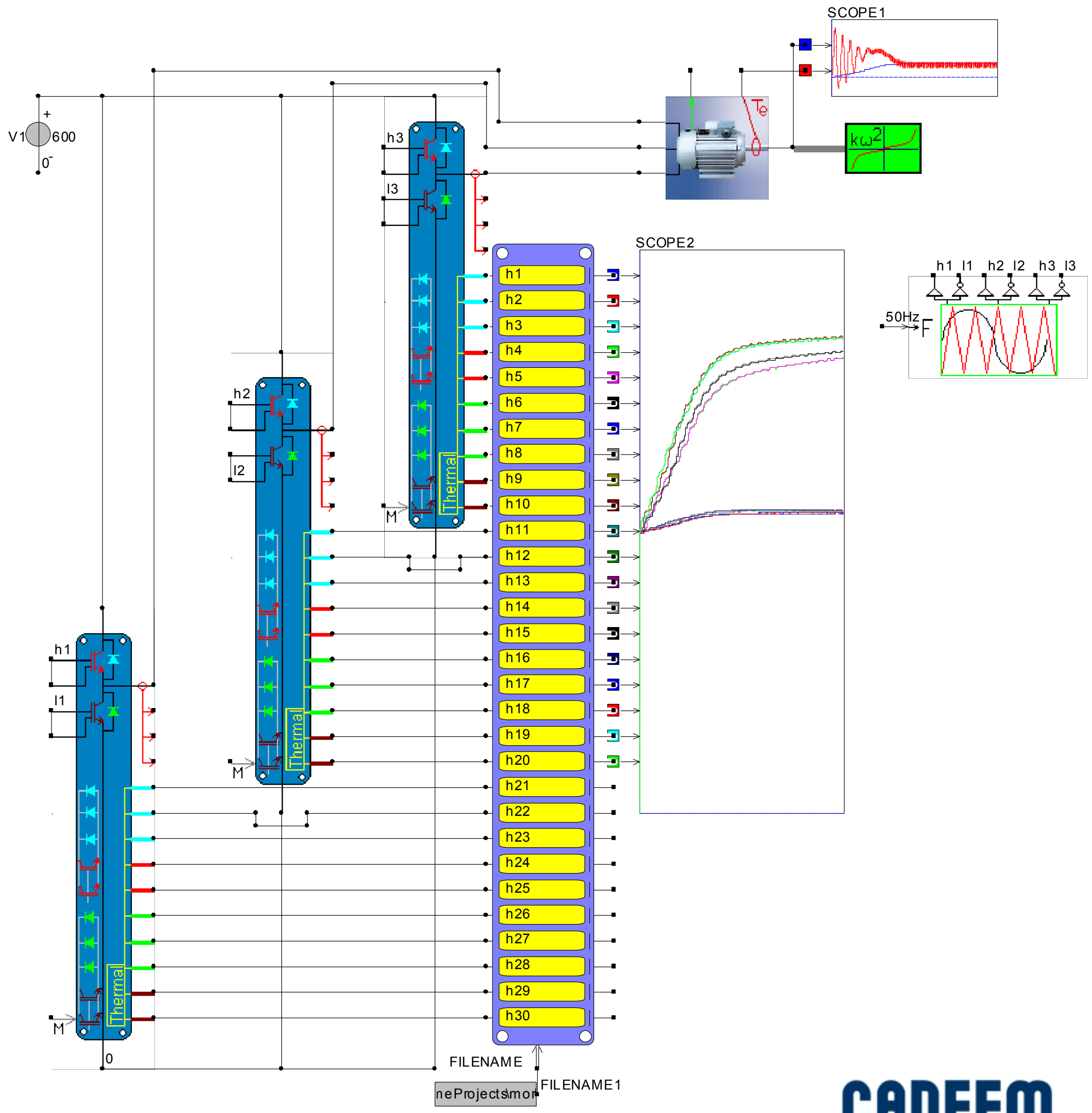
CADFEM

Electrothermal Simulation of IGBTs

- Eurosime 2008, Daimler, simulation with CASPOC

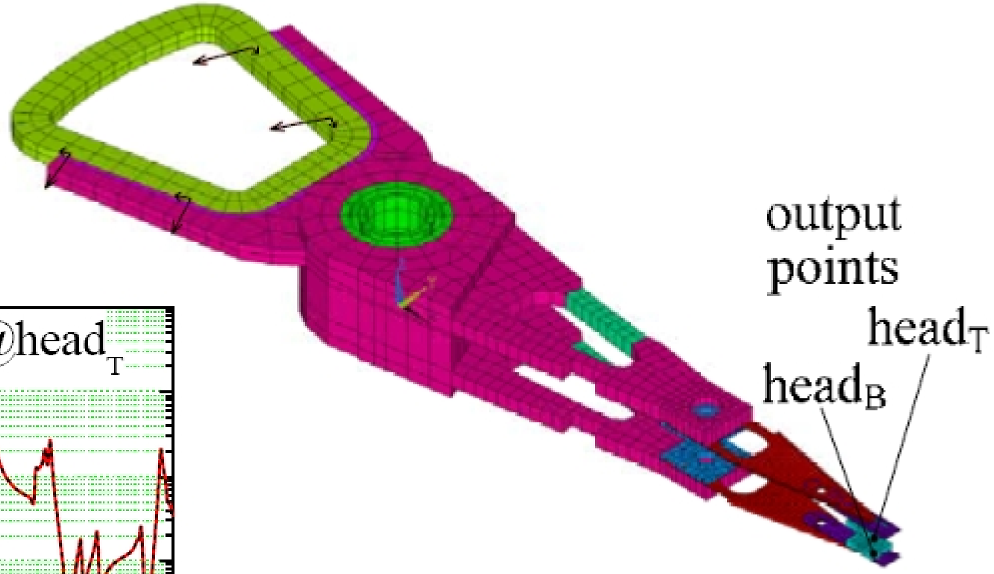


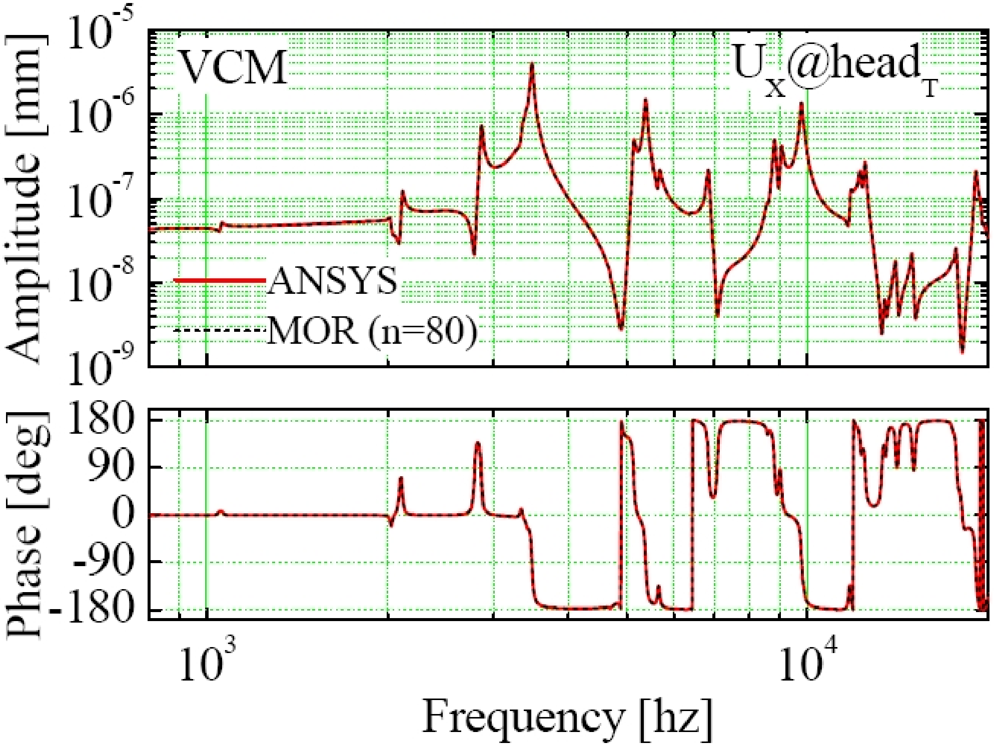




HDD actuator and suspension system

- Prof J. S. Han. Transactions of the KSME, A, Vol. 31, No. 5, pp. 541-549, 2007.

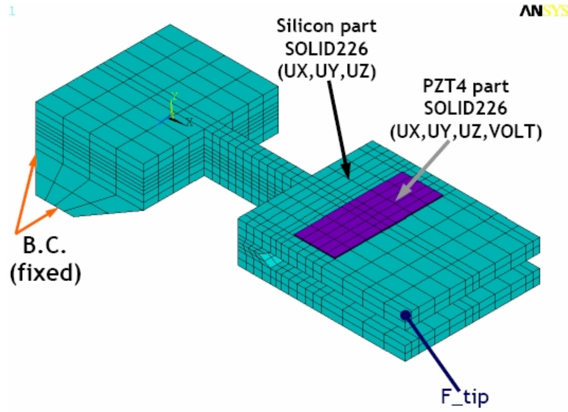




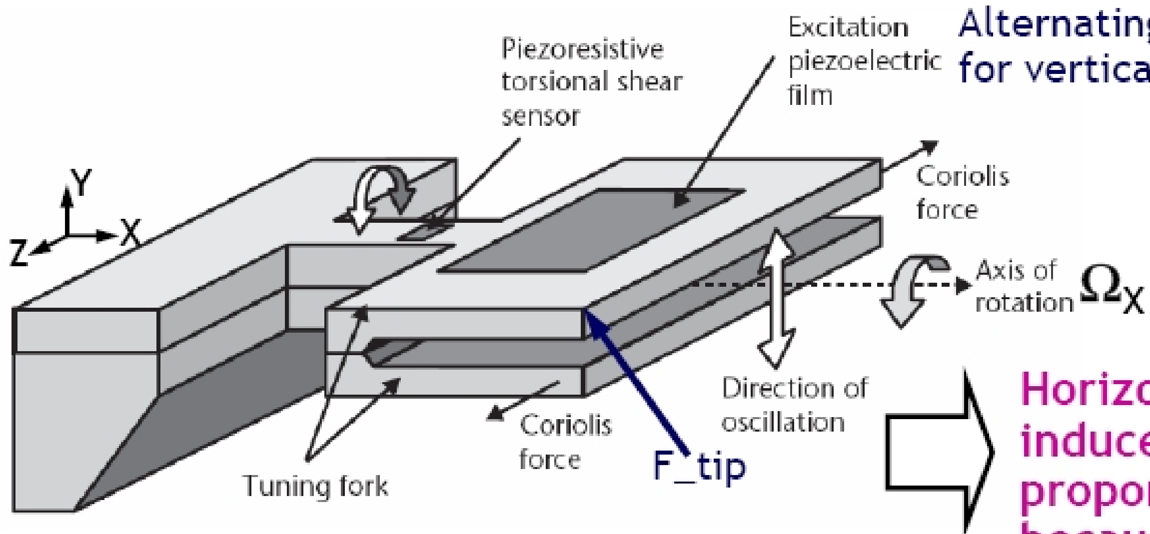
Piezoelectric Angular Rate Sensor with Coriolis Effect

- Prof J. S. Han, KSME 2008.

$$\begin{bmatrix} M & 0 \\ 0 & 0 \end{bmatrix}\begin{Bmatrix} \ddot{u} \\ \ddot{V} \end{Bmatrix}+\begin{bmatrix} E & 0 \\ 0 & 0 \end{bmatrix}\begin{Bmatrix} \dot{u} \\ \dot{V} \end{Bmatrix}+\begin{bmatrix} K & K^{z} \\ K^{zT} & K^{d} \end{bmatrix}\begin{Bmatrix} u \\ V \end{Bmatrix}=\begin{Bmatrix} f \\ l \end{Bmatrix}$$



- μ-Gyroscope
  : angular velocity μ-sensor using Coriolis effect



Alternating voltage (1 V) for vertical excitation (U_Y)

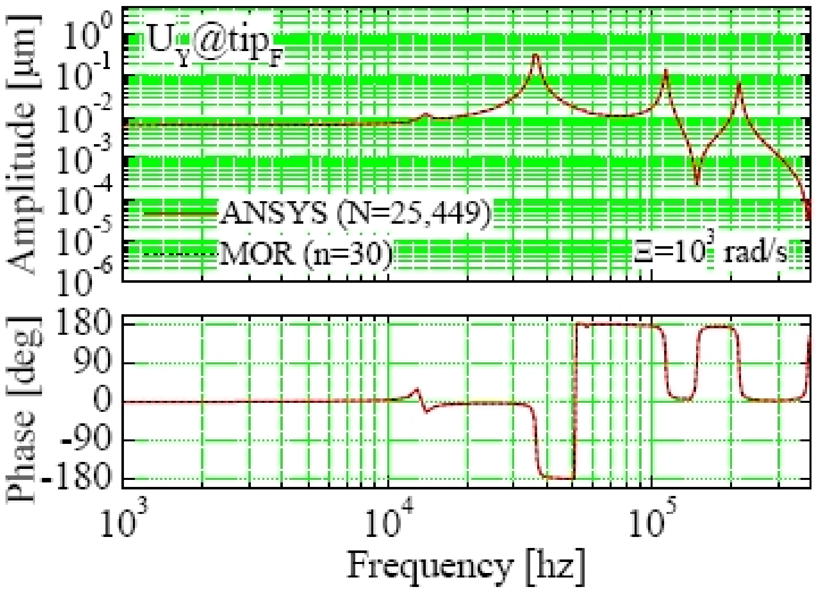
Horizontally induced vibration (U_Z) proportional to Ω_X because of Coriolis effect

Piezoelectric Angular Rate Sensor with Coriolis Effect

- Frequency responses (Ω_X=1,000 rad/s)

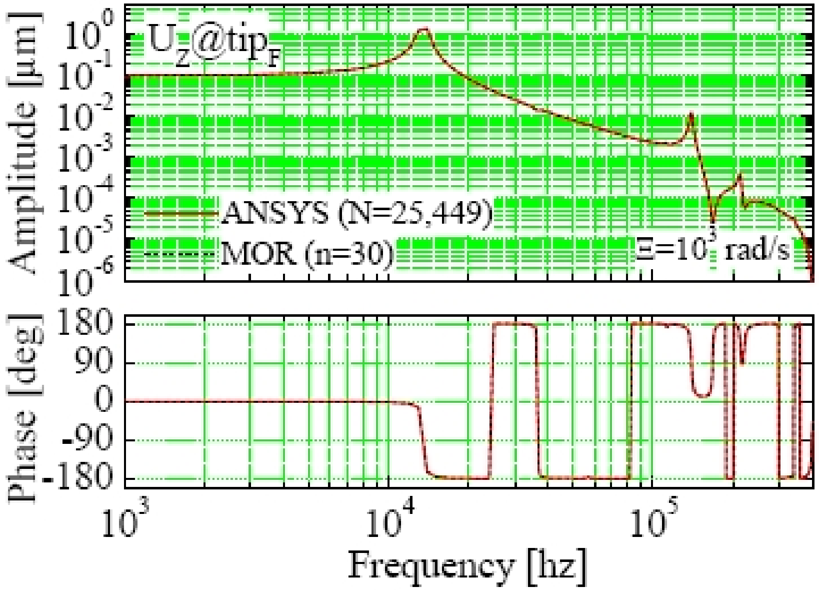
•U_Y@tip$_F$

vertical excitation



•U_Z@tip$_F$

Horizontally induced vibration



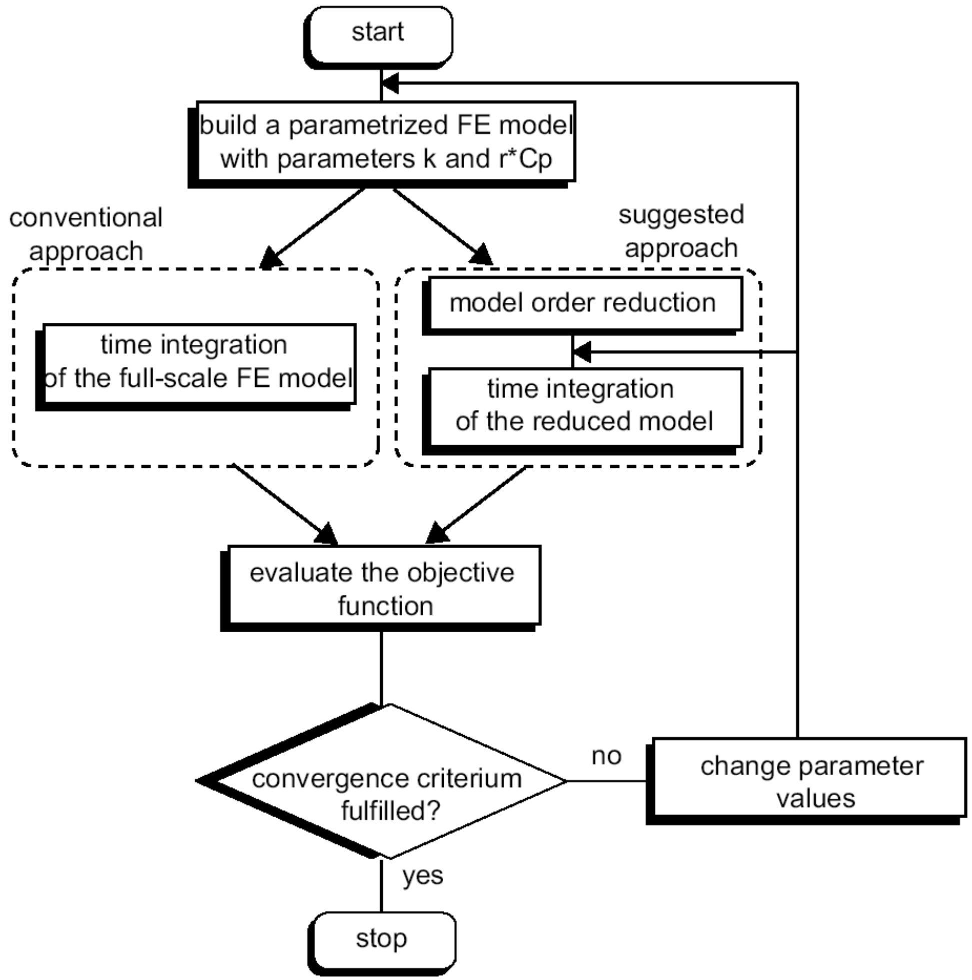
- No. of DOFs: 25,449

Prof. J S Han@ANU

CADFEM

Model Reduction as Fast Solver

- Simulation of the reduced model is a few seconds.
- Arnoldi Process is fast:
  - Transient and harmonic response analysis for the cost comparable with that of a static solution.
- It is advantageous to use MOR even the reduced model is used only once:
  - Design,
  - Geometry optimization.

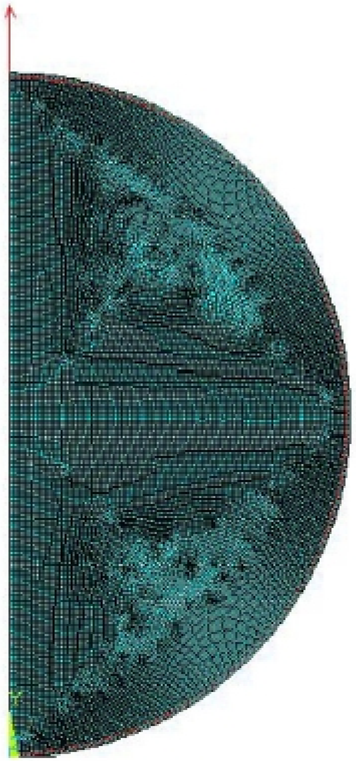


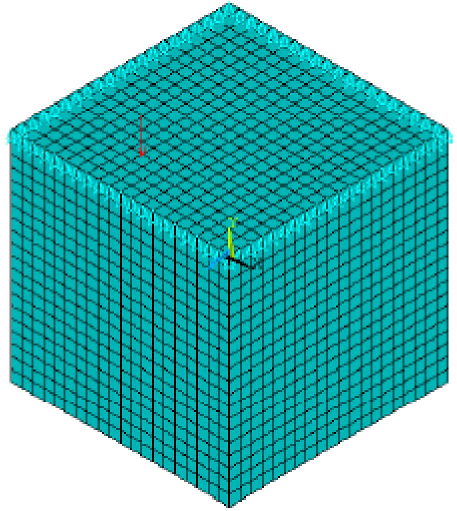
CADFEM

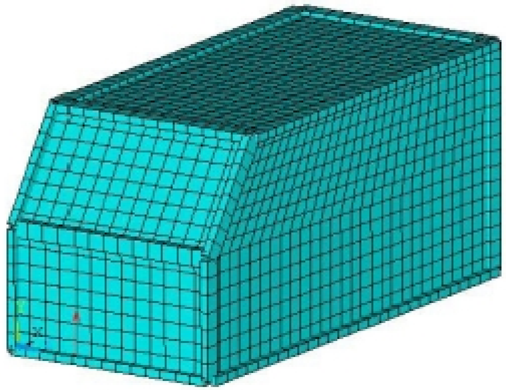
NVH Benchmarks in Thesis

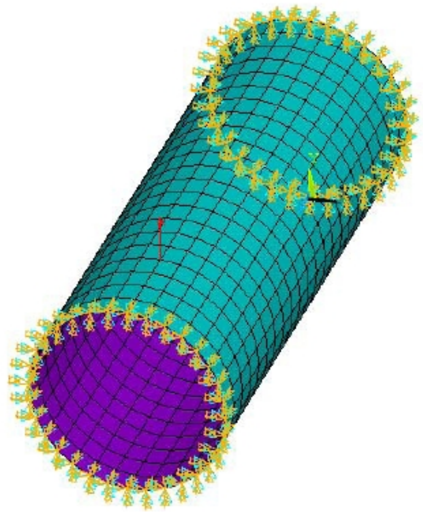
ANSYS

- The 2D “Acid-Test”
- 3D Plate backed air filled cavity
- 3D Plate backed Rectangular Water Filled Cavity
- Cylinder enclosing an air-filled cavity
- Demonstrator Structure: Adhesive Bonded Joint



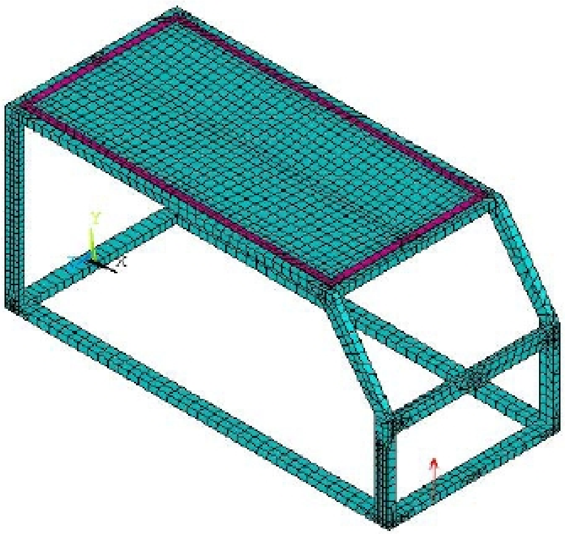


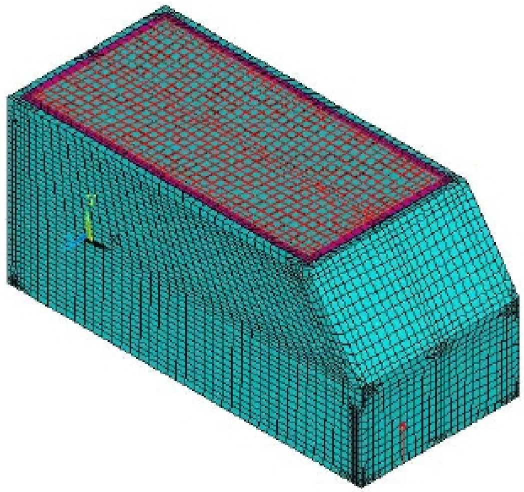




CADFEM

Adhesive Bonded Joint Benchmark

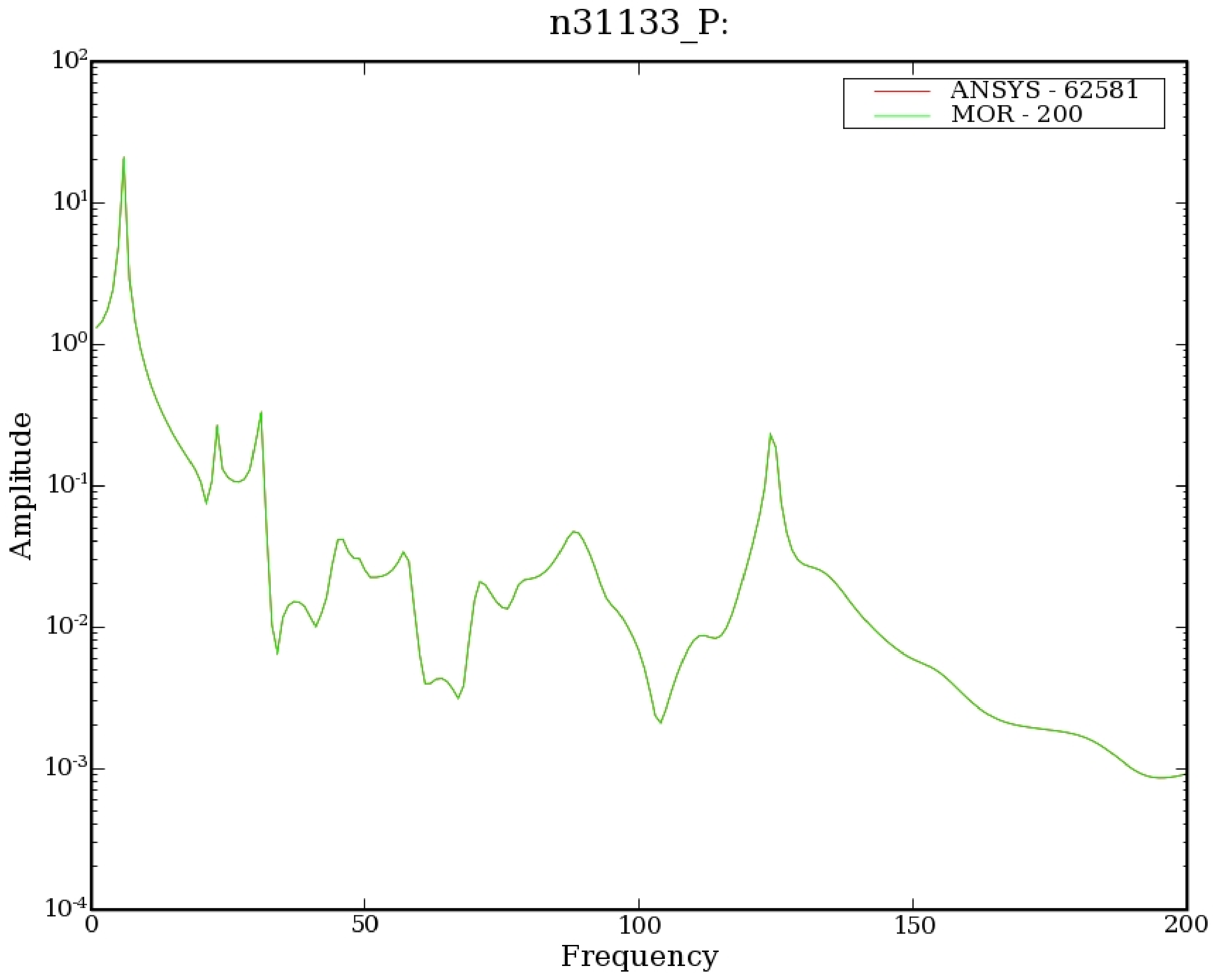




- Mechanical Structure - SHELL181
- Adhesive – SOLID45
- Fluid – FLUID30
- Single excitation point
- Global and local damping

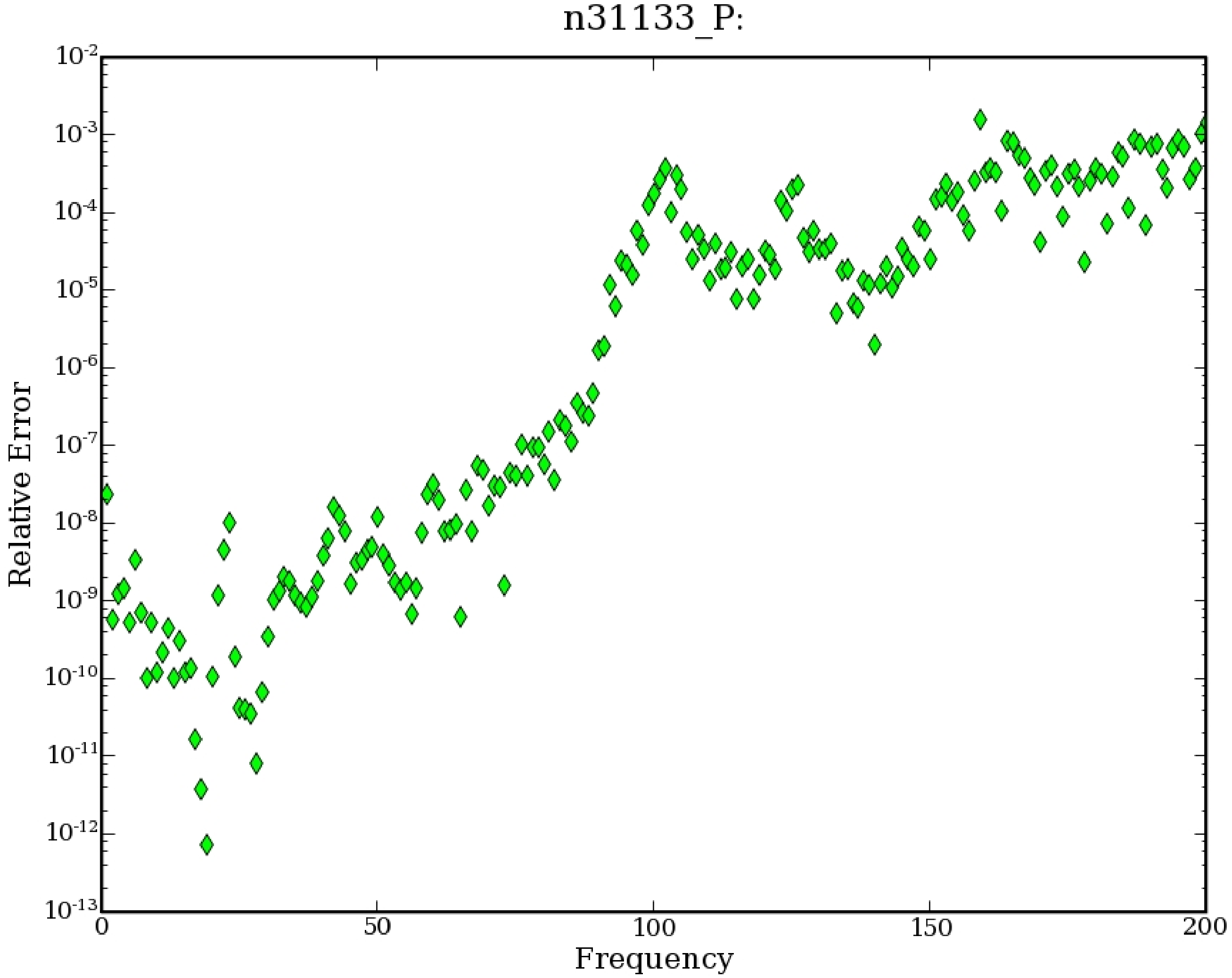
CADFEM

Comparison

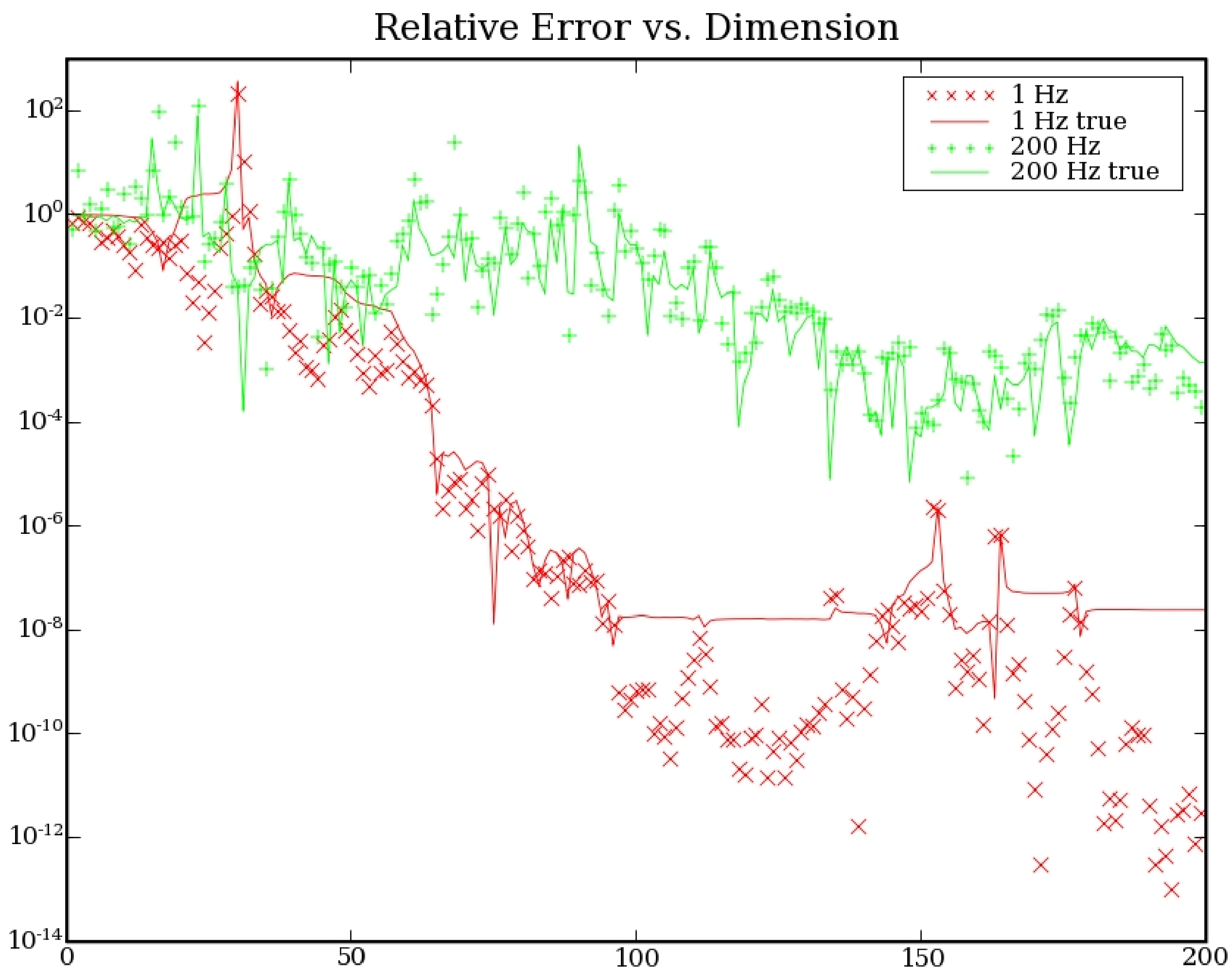


CADFEM

Comparison – Relative Error



Error Indicator



- True Error

$$E_r(s) = \frac{|H(s) - H_r(s)|}{|H(s)|}$$

- Error Indicator

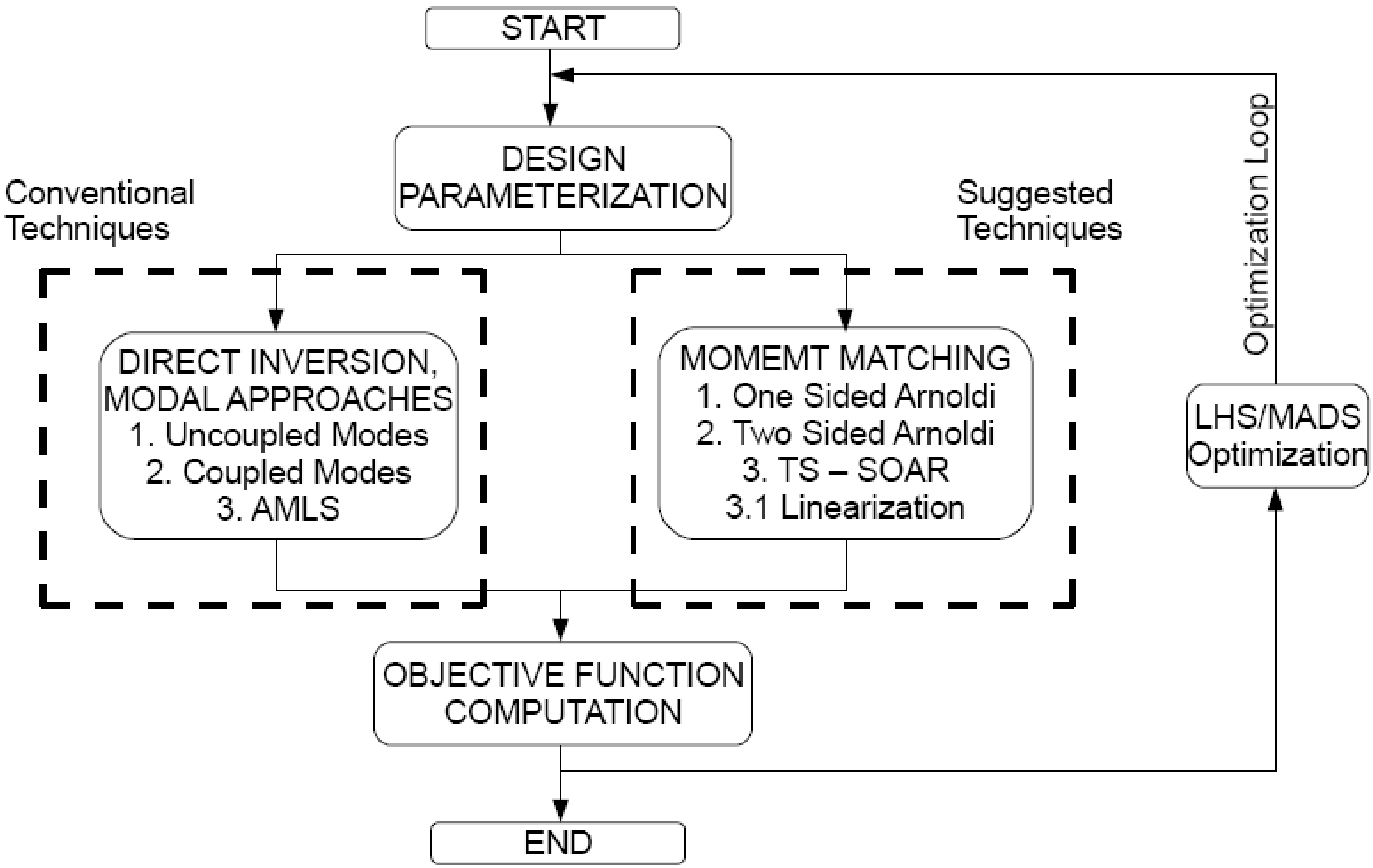
$$\hat{E}_r(s) = \frac{|H_r(s) - H_{r+1}(s)|}{|H_r(s)|}$$

$$E_r(s) \approx \hat{E}_r(s)$$

Timing

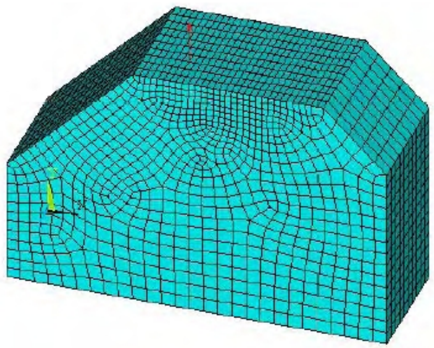
- Problem in ANSYS
  - 37988 elements, 38712 nodes, 62581 free DoFs
- Full solution in ANSYS for 200 frequencies
  - 16695 s – 4.6 hours – 83 s per frequency
  - Proportional to the number of frequencies
- MOR for ANSYS
  - Reading ANSYS files – 3 s
  - Model reduction – 170 s
  - Proportional to the number of vectors
- Simulation of the reduced model
  - 4 s

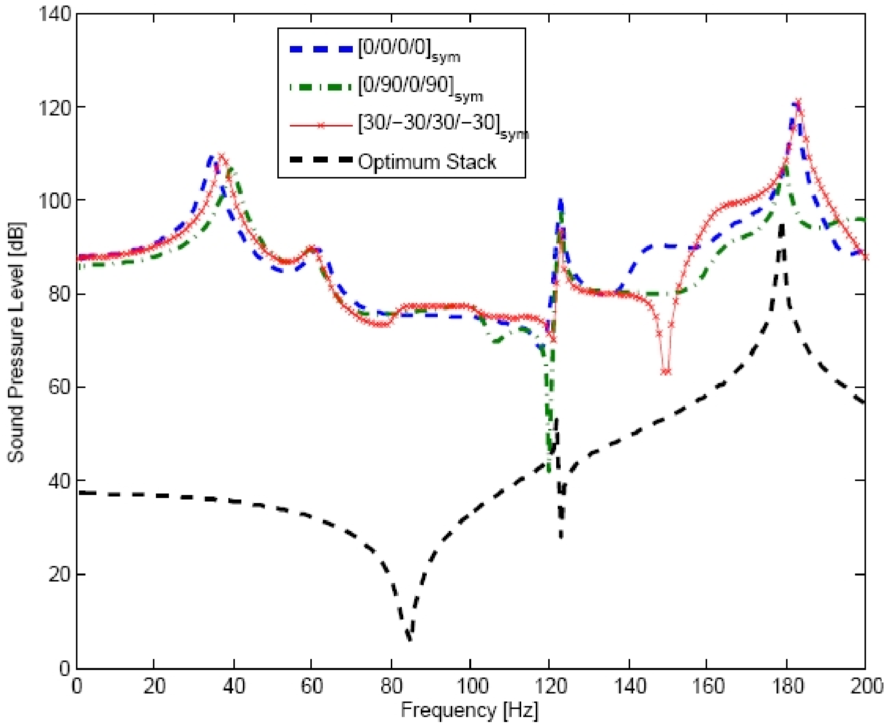
NVH Optimization

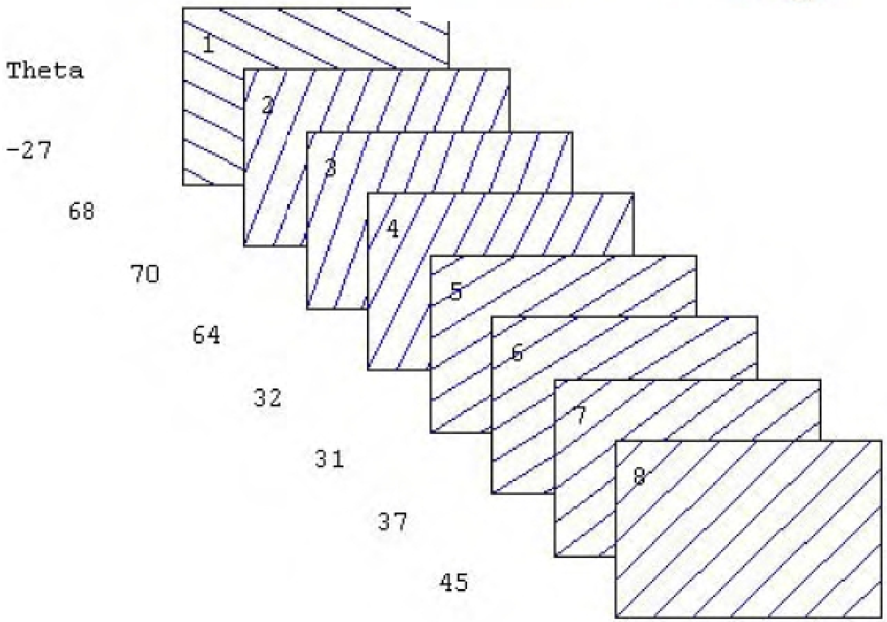


NVH Vibro-Acoustic Optimization

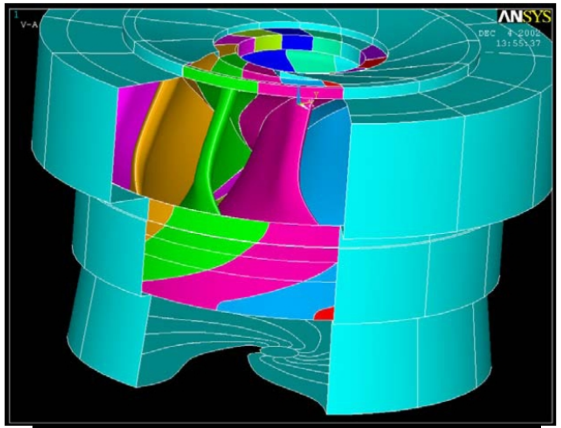
- SHELL181 to model the layered composite
- Stack of eight layers
- To find optimal lamination

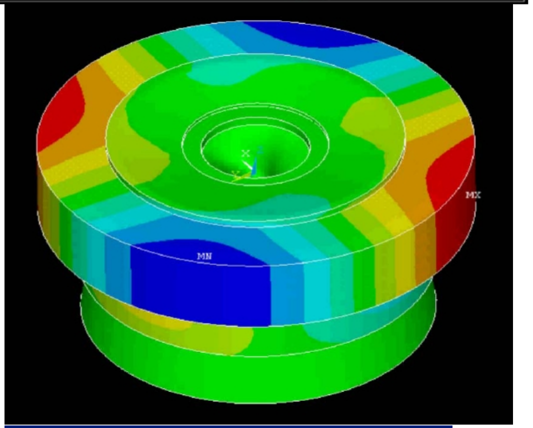




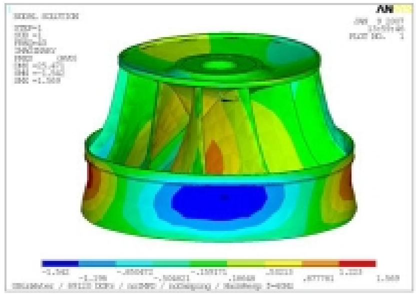


Fluid Structure Interaction at Acoustic Level

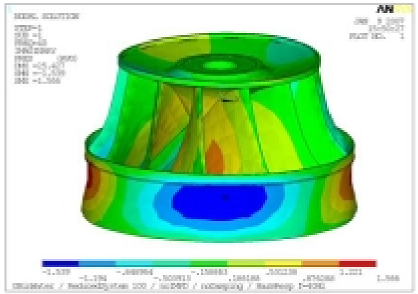




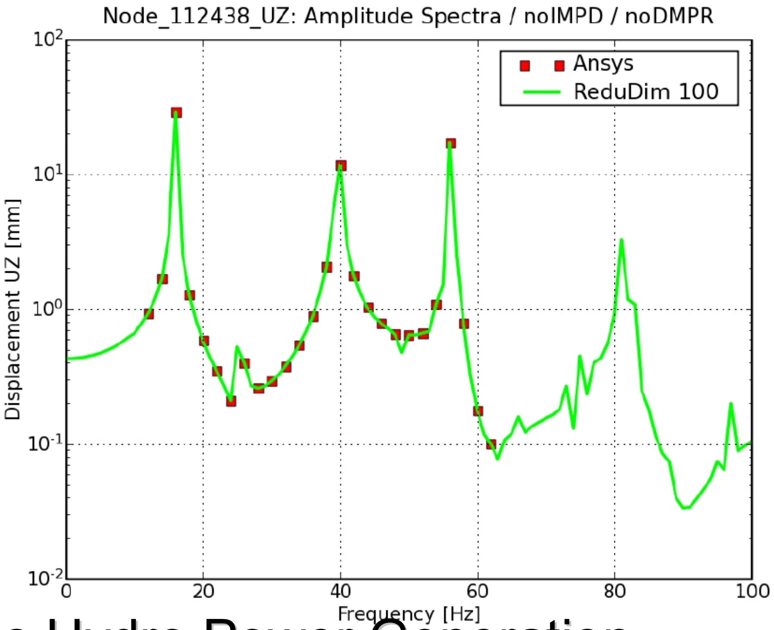
VOITH SIEMENS
HYDRO POWER GENERATION



ANSYS 90.000 DOFs´



MOR 100 DOFs



By courtesy of Voith Siemens Hydro Power Generation GmbH & Co. KG

CADFEM

Conclusion

- Model reduction is an excellent tool to speed up NVH simulation

- Software for ANSYS is available:
  - MOR for ANSYS

- More information:
  - http://ModelReduction.com