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Analysis of nonlinear vibrations in jointed gas-turbine structures

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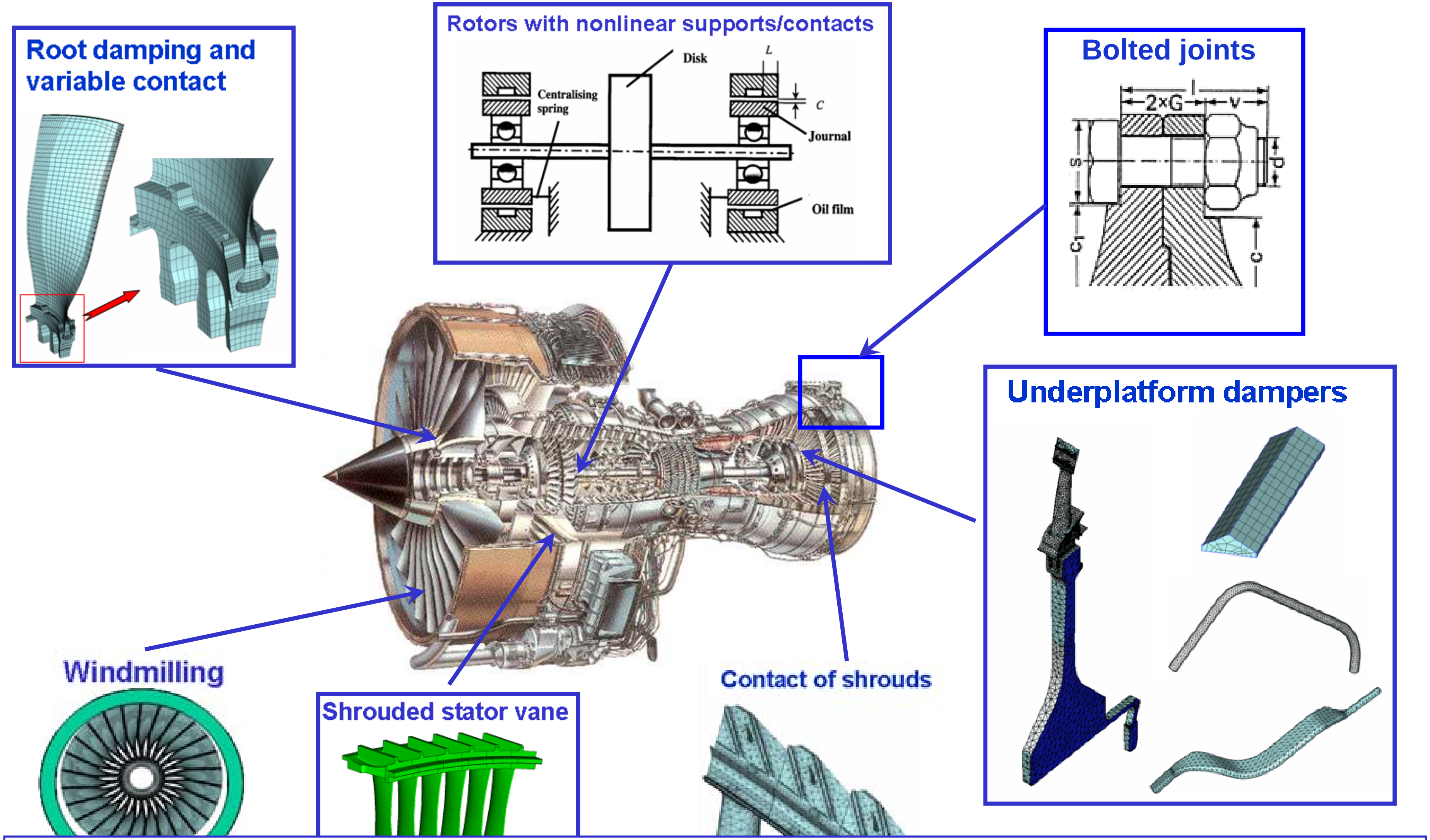
Contact interfaces in gas-turbine structures

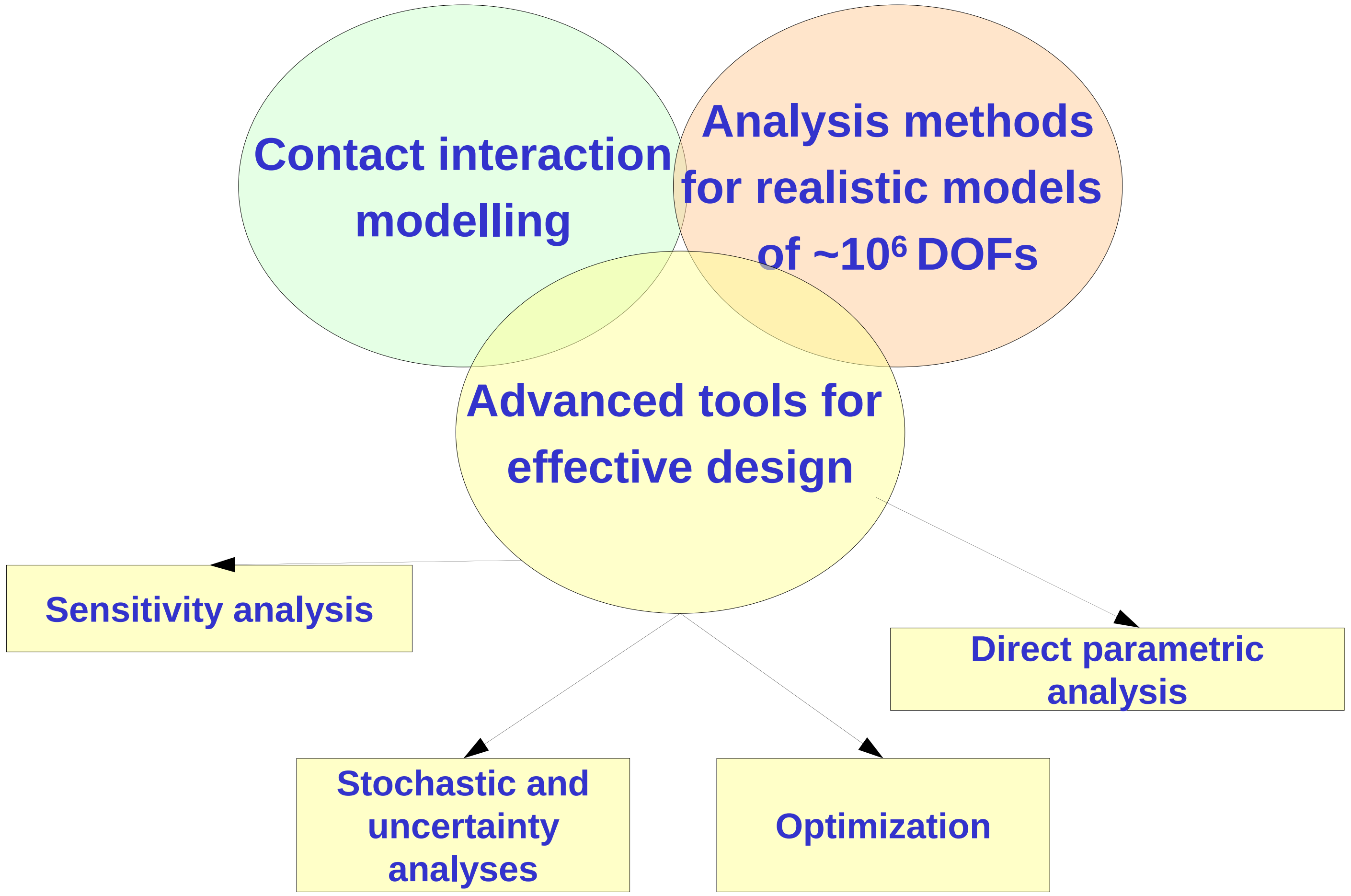


The challenge is to analyse fast and accurately nonlinear dynamics of assembled large-scale models of structures with contact interfaces

A blade containment test: windmilling

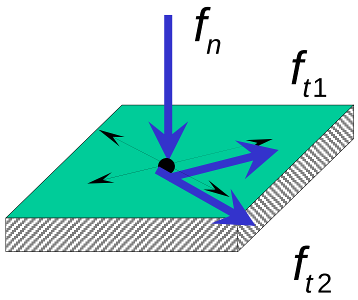
Methodology for predictive analysis of dynamic problems in gas-turbine structures

Major components of the methodology developed at Imperial College

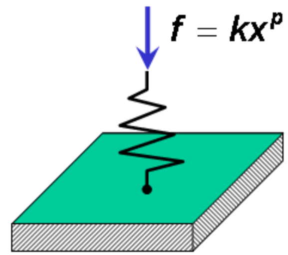


Major types of contact interactions modelled

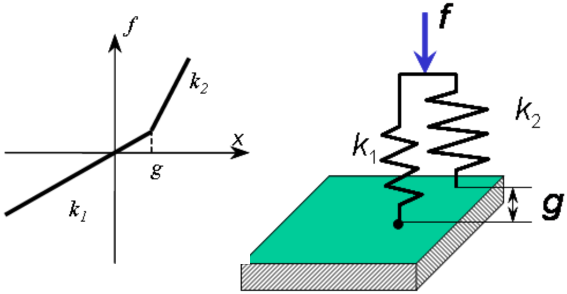
Friction contact: 3D motion with variable normal load



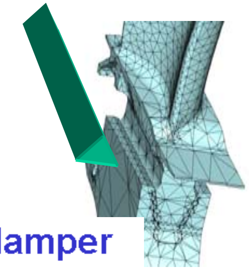
Generalised nonlinear spring element: any polynomial nonlinearity

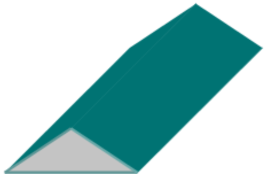


Bilinear spring and gap



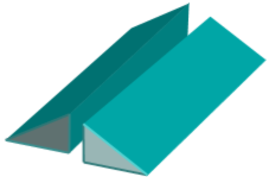
Specialized elements:



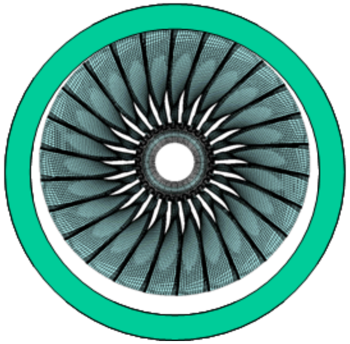


Cottage-roof damper

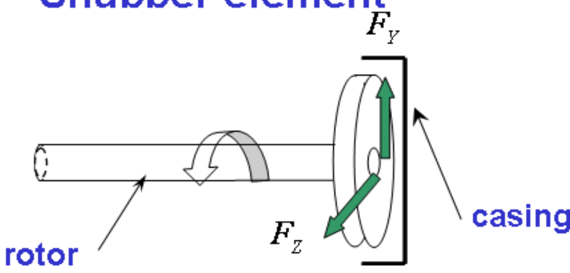
Split damper



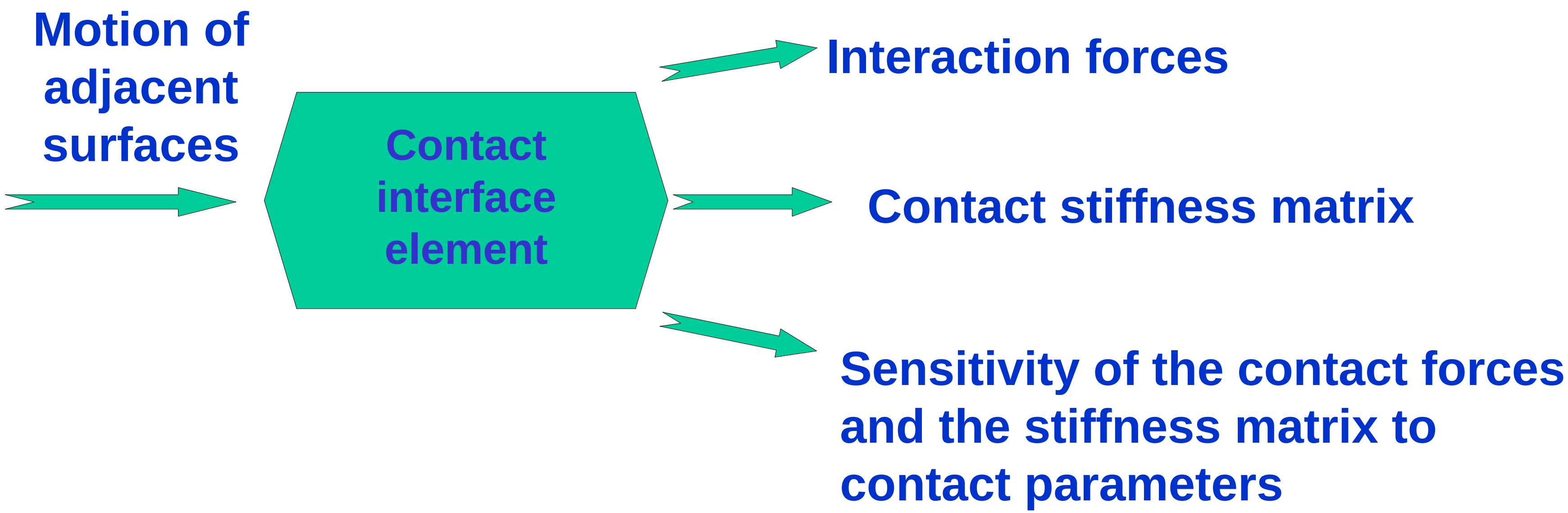
Bladed-disc-casing contact



Snubber element

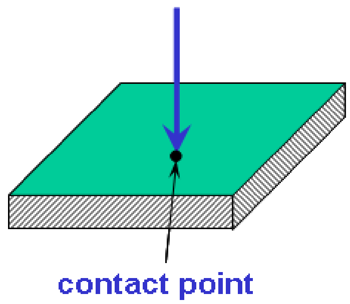


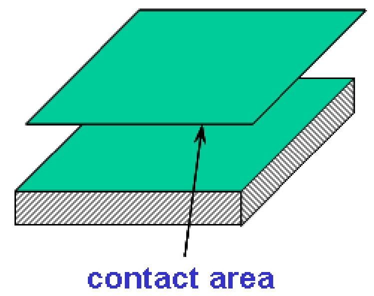
Breakthrough in the analysis of periodic steady-state vibrations: analytically derived contact interface elements



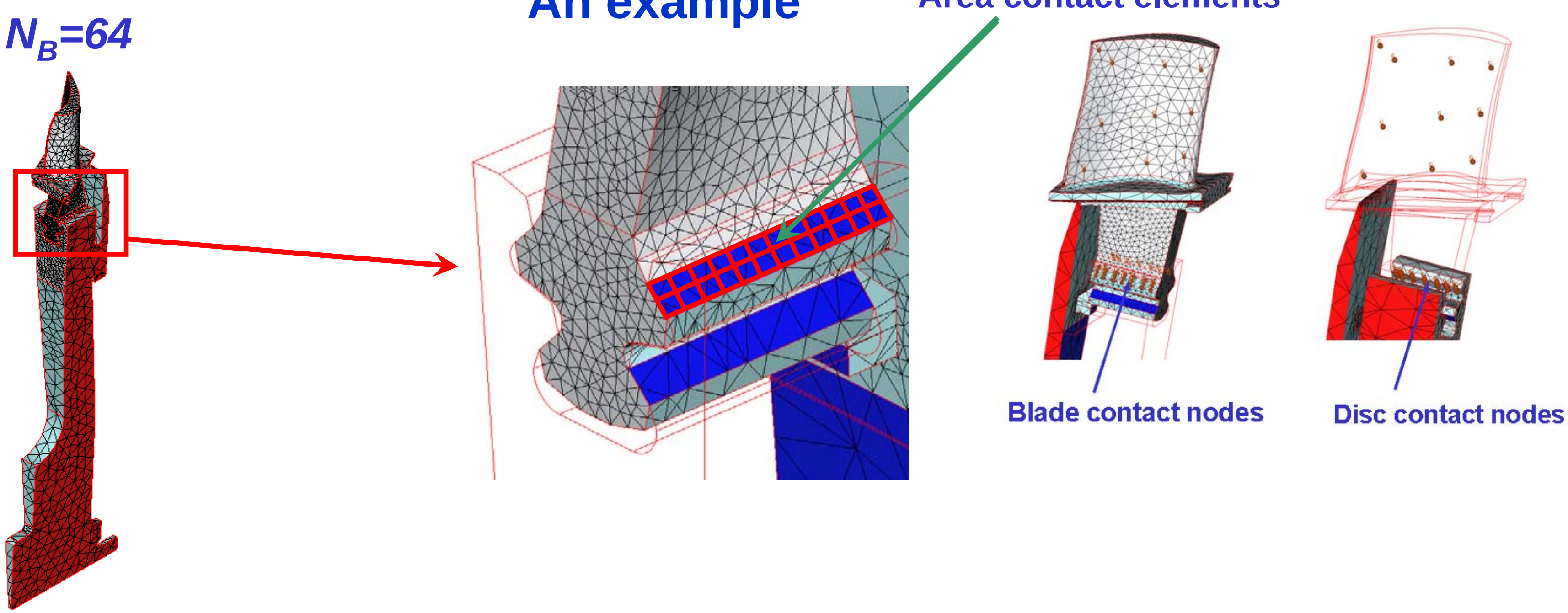
Expressions are obtained in analytical form ⇒ EXACT + extremely FAST calculations

Description of contact interface interactions by the contact elements



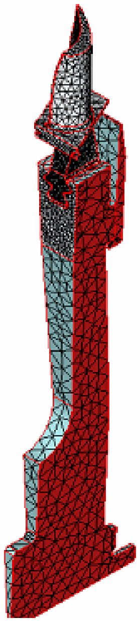


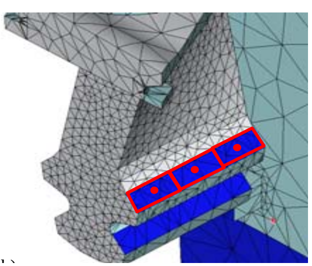
An example

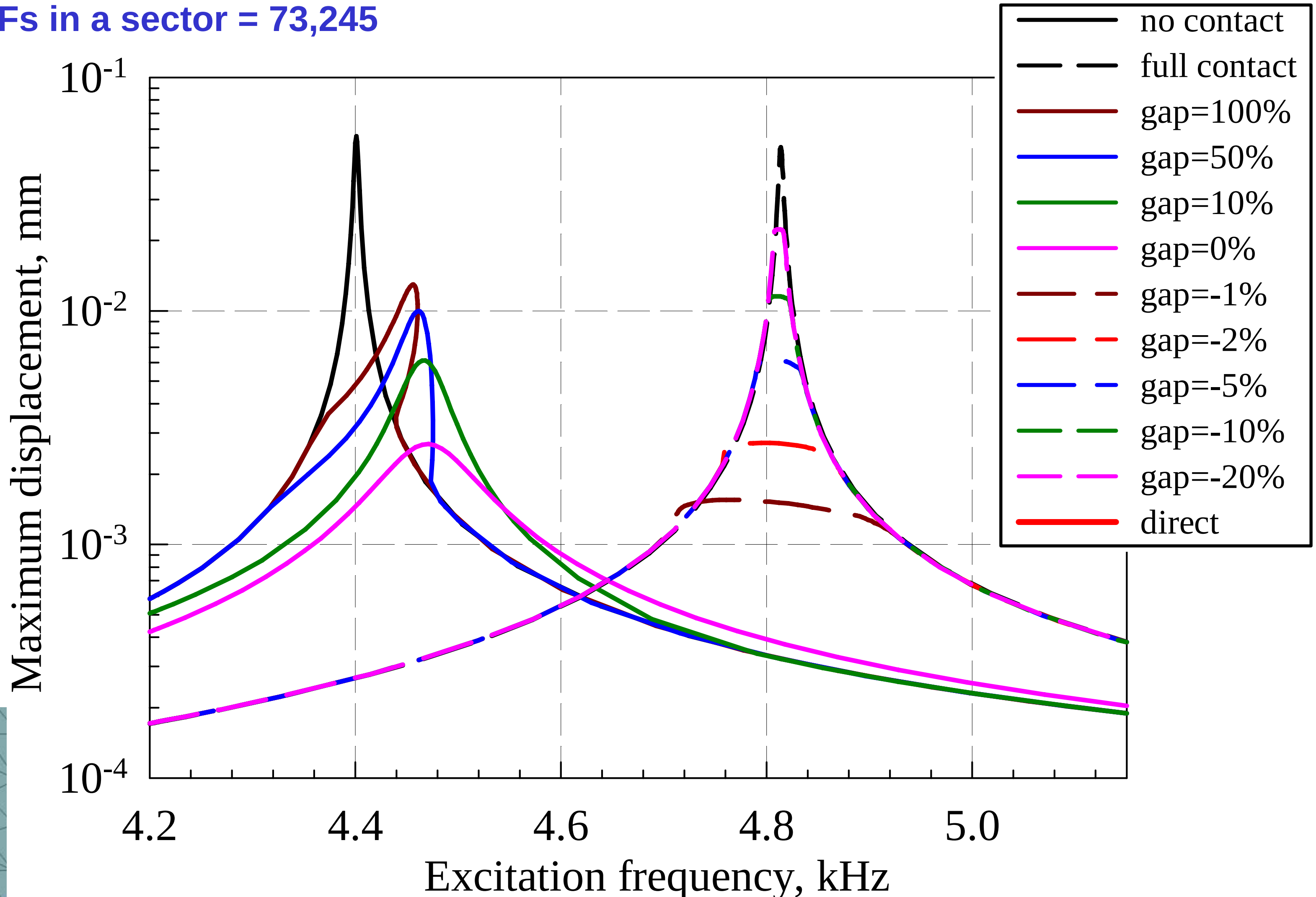


Analysis of forced response: blade root damping

Number of DOFs in a sector = 73,245

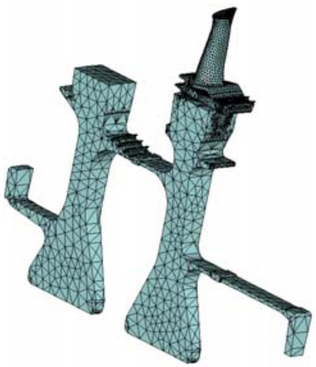




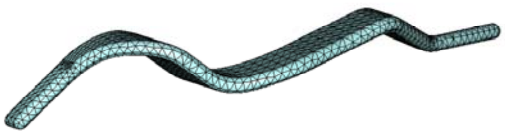


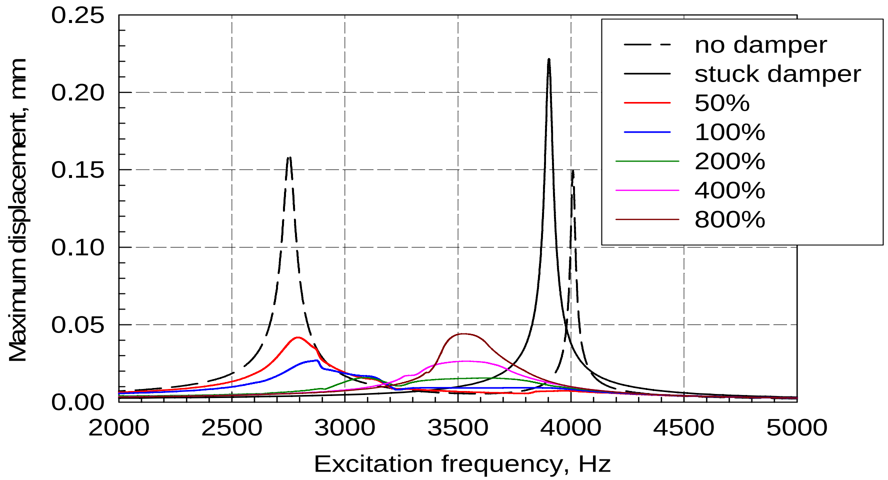
A bladed disc with u/p dampers

FE bladed disc sector model: 309,990 DOFs

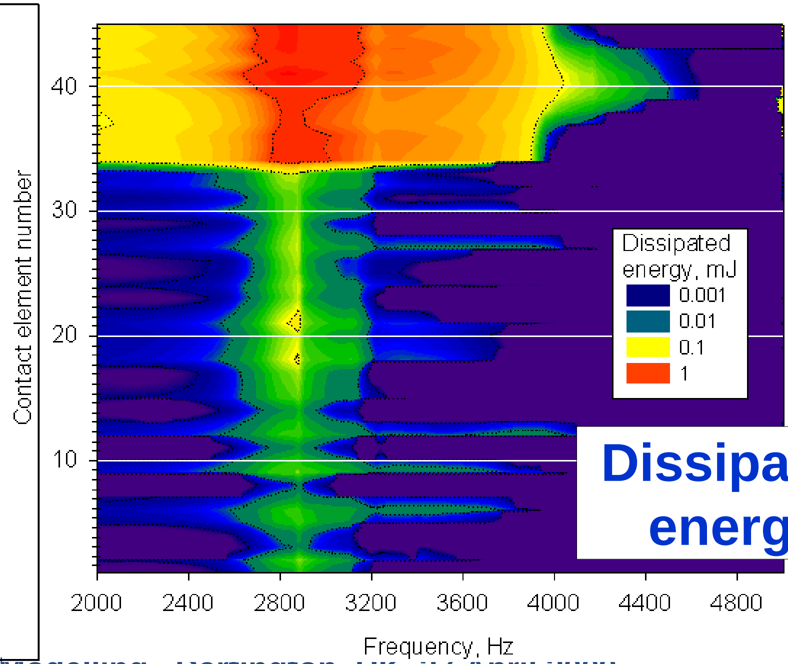


Strip damper: 24,753 DOFs





Contact conditions

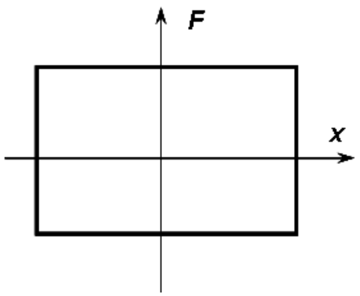


Dissipated energy

New friction models

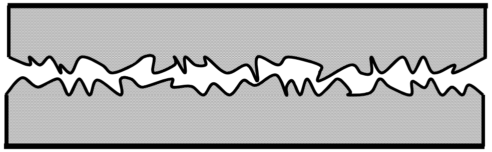
Amonton/Coulomb model (1699/1785)

$$F = \mathrm{sgn}(\dot{x})\mu N$$

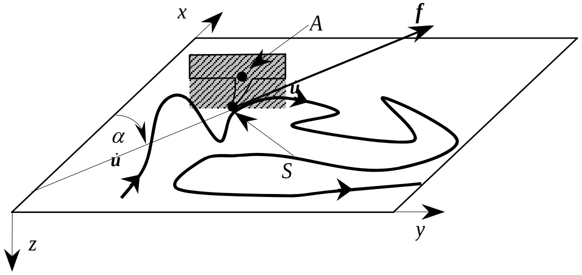


Disadvantages: disregard of normal load variation and history of motion, applicable only to large and 1D displacements, discontinuous

Rough surface contacts



3D motion of a contact point

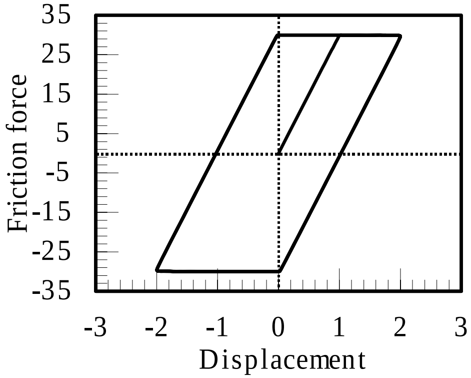


Capabilities of new models:

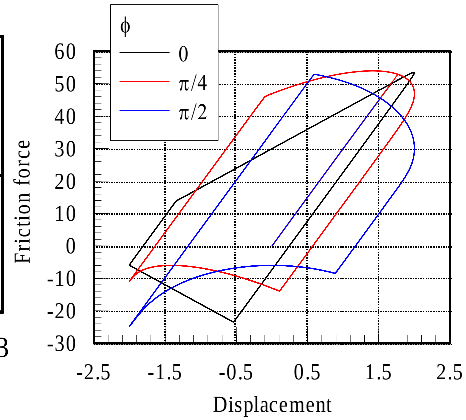
1) arbitrary 3D motion, normal load variation including contact-separation
2) accounting for stiffness due to contact surface roughness
3) anisotropy and inhomogeneity of the friction parameters over contact area
4) time variation of friction parameters (due to variation in temperature, wear, lubrication, etc.)

Examples of friction force modelling by new models

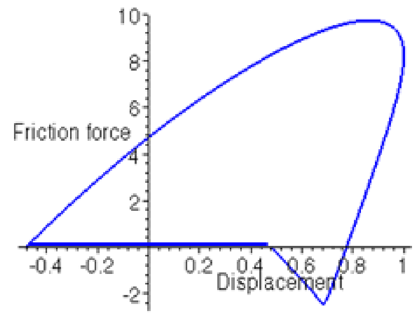
Constant normal load



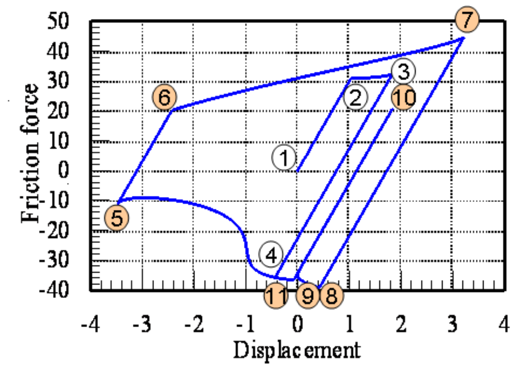
Variable normal load



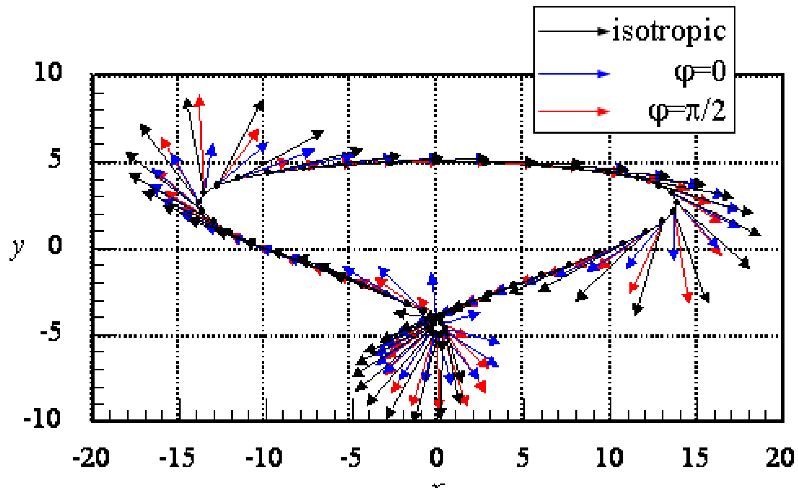
Variable normal load with separation



Multiharmonic vibration



Trajectory and friction force vector (different anisotropy properties)



Advanced tools for effective design

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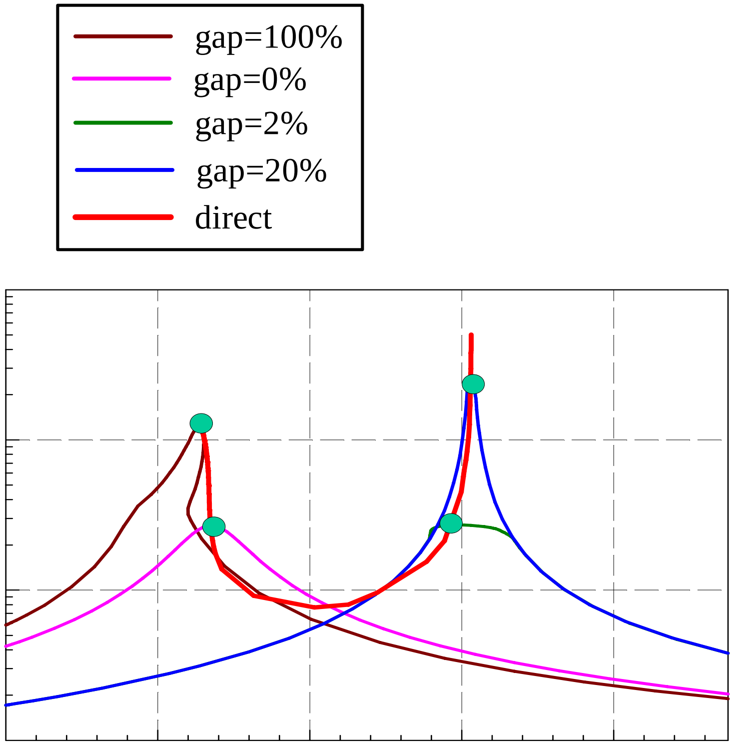
Direct parametric analysis



Conventional forced response analysis:

Frequency response is calculated to obtain only resonance peak frequency and response level.

Many analyses are needed for different parameter values

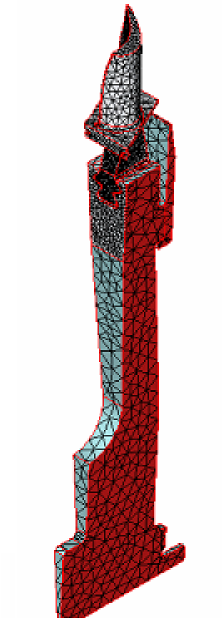
Direct parametric analysis:

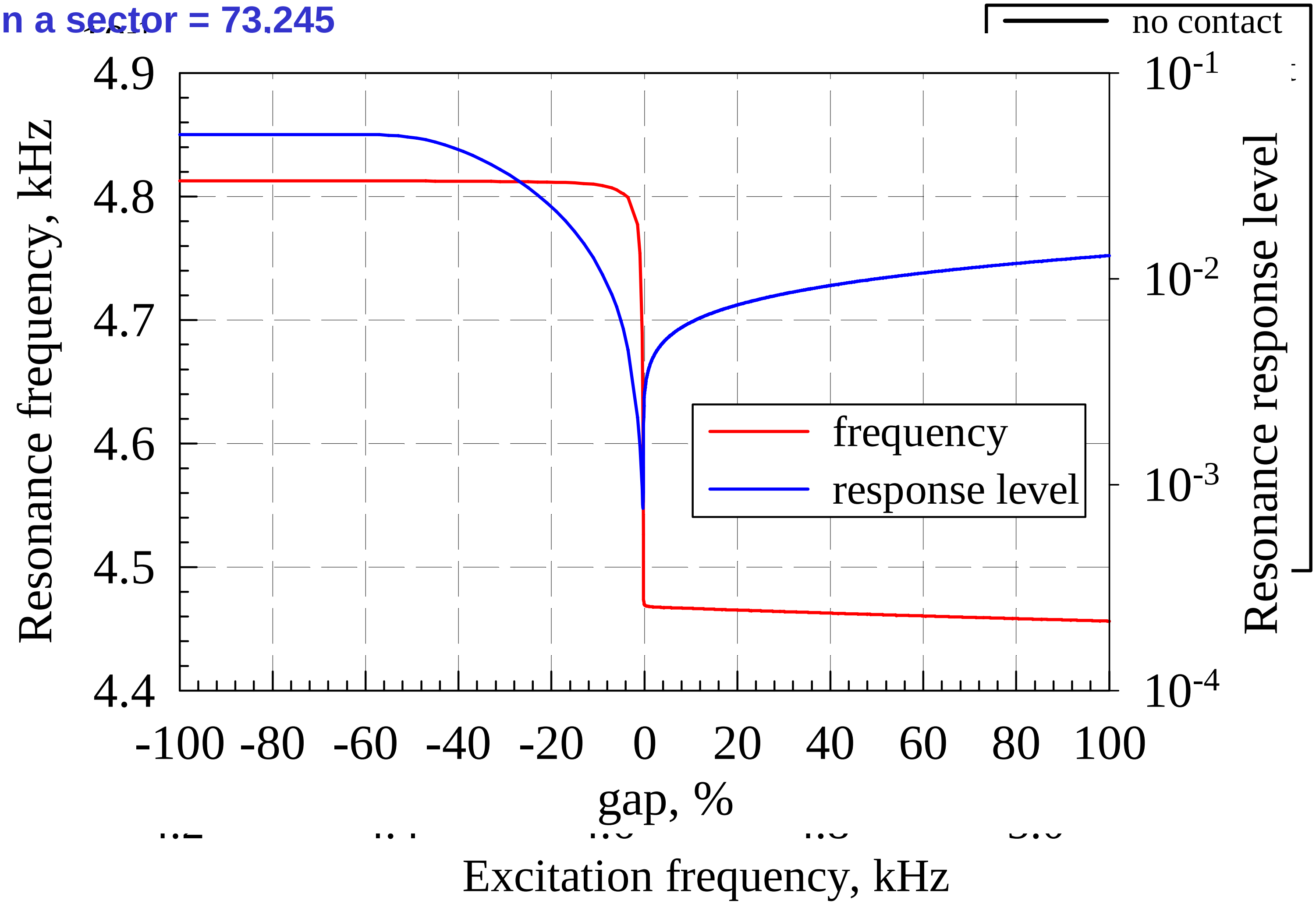
The resonance peak frequency and response level are calculated directly as functions of design parameters

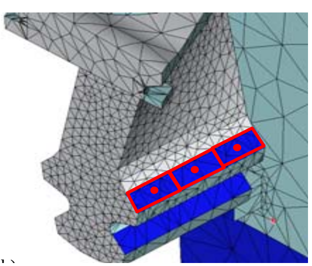
$$\begin{cases} \omega^{res}(\lambda) = \omega^{res}\left(\boldsymbol{b}(\lambda)\right) \\ \boldsymbol{a}^{res}(\lambda) = \boldsymbol{a}^{res}(\boldsymbol{b}(\lambda)) \end{cases}$$

Direct parametric analysis: blade root damping

Number of DOFs in a sector = 73.245

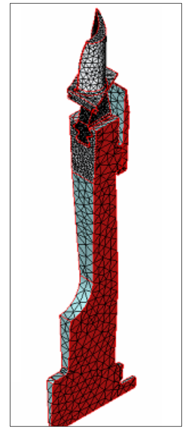


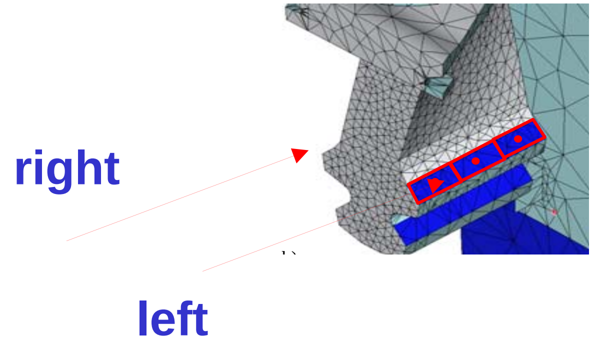


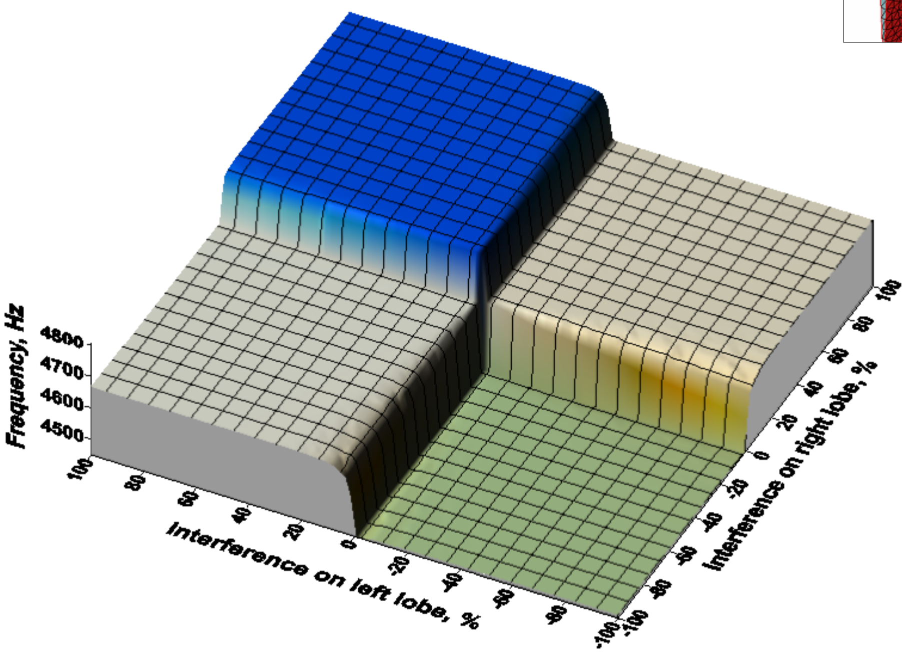


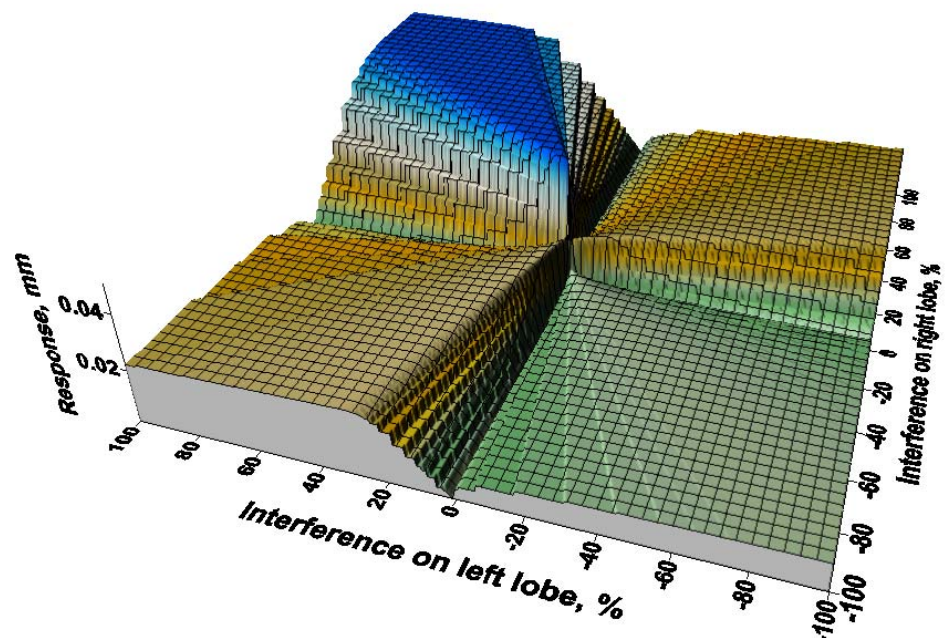
Computation time: 10 min (together with the sensitivity)

Resonance peak amplitude and frequency: dependency on the interference values at the contact interfaces









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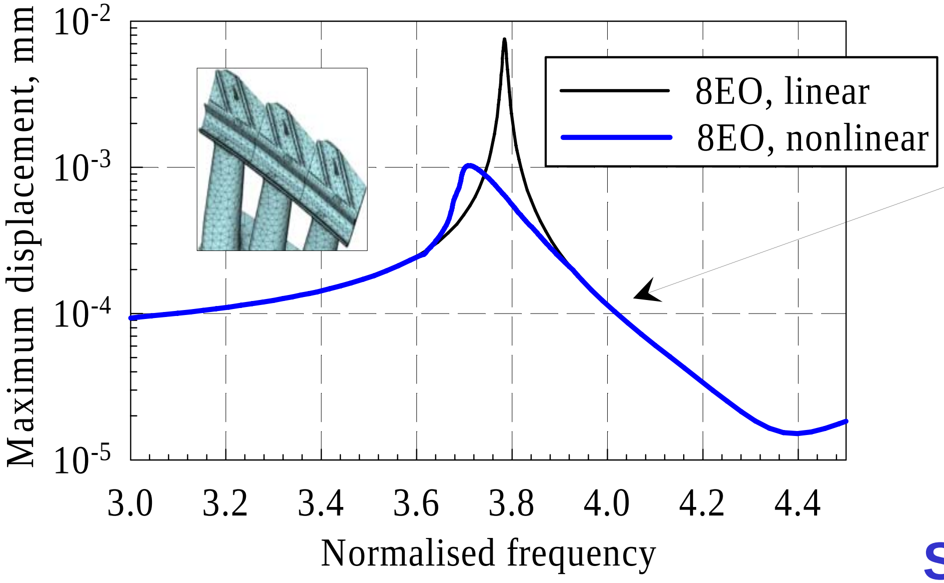
Sensitivity analysis for forced response



Forced response:

$$x(\omega)$$

First-order sensitivity coefficients

$$\frac{\partial x(\omega)}{\partial \lambda}$$

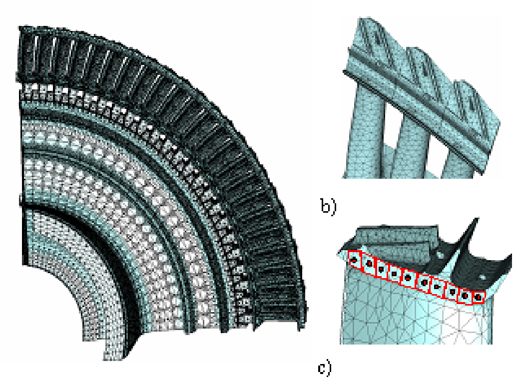
Second-order sensitivity coefficients

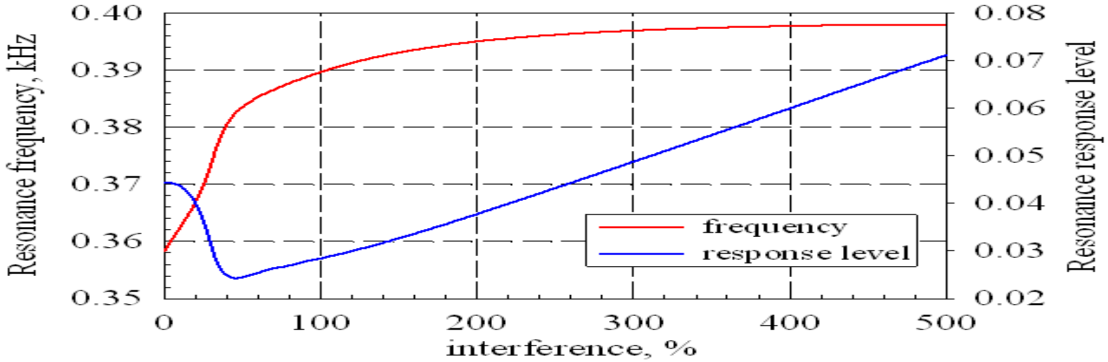
$$\frac{\partial^2 x(\omega)}{\partial \lambda^2}$$

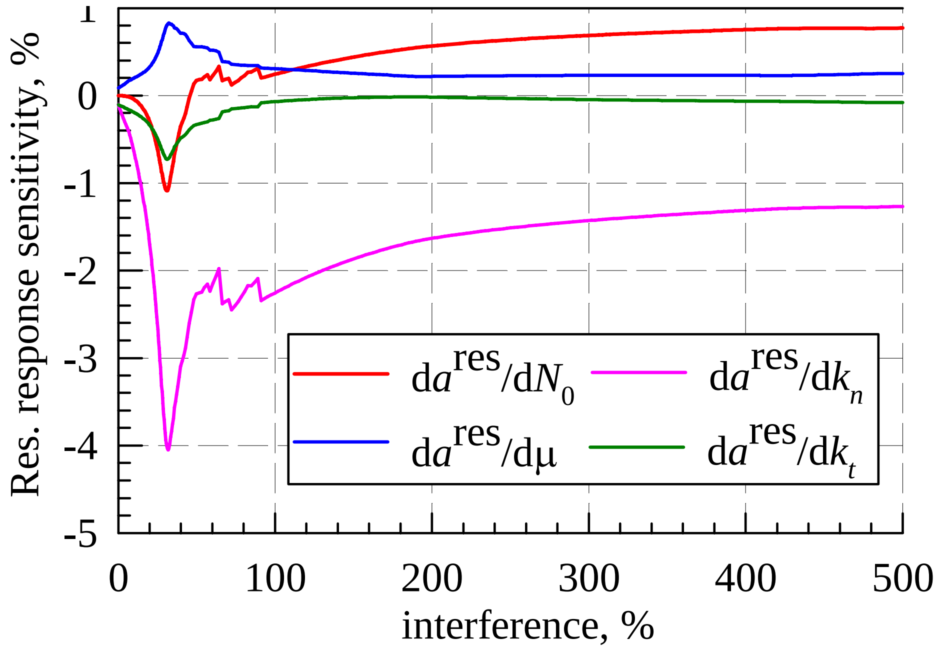
λ = clearance, interference, friction coefficient, contact stiffness, mass of u/p damper, or other design parameters and their combinations

Example: forced response sensitivity to contact interface parameters for a shrouded bladed disc

N_B=92







The analytical derivation provides outstanding qualities of the method: very fast speed of calculations and high accuracy

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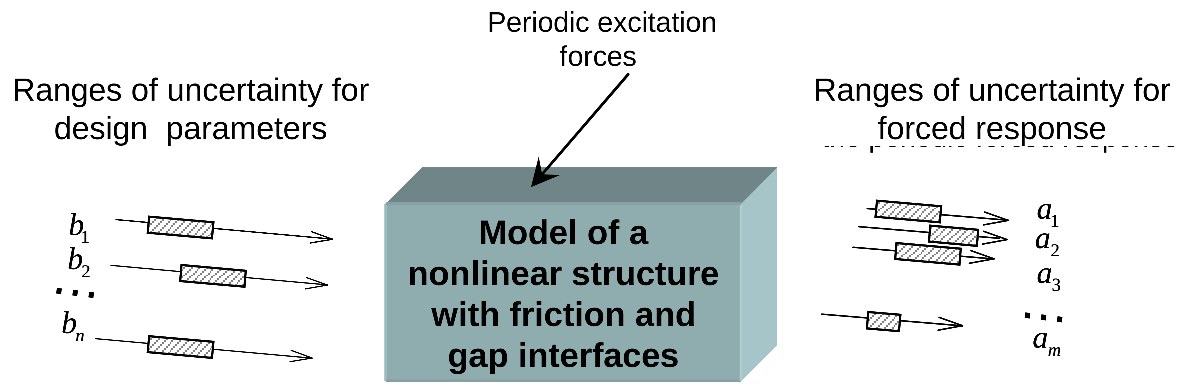
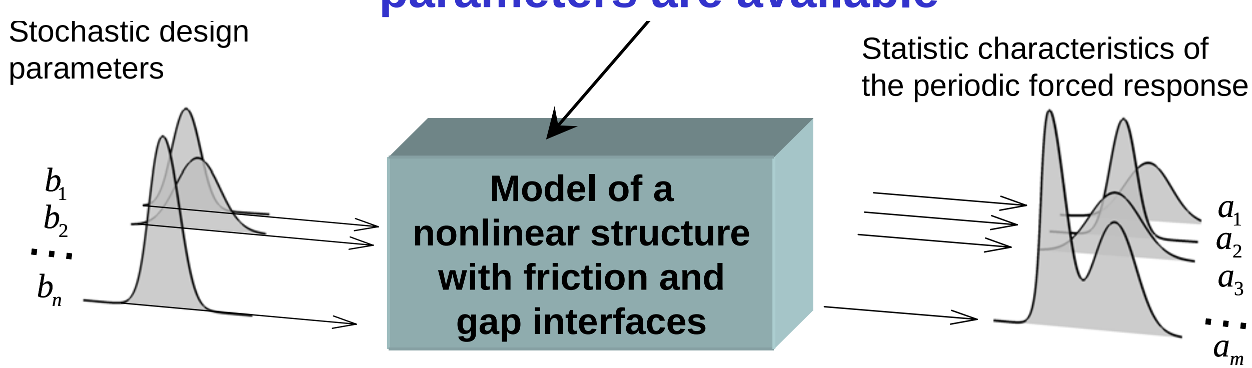
Analysis of effects of design parameters uncertainty and variability on forced response

Uncertainty analysis of forced response for given design parameter uncertainties

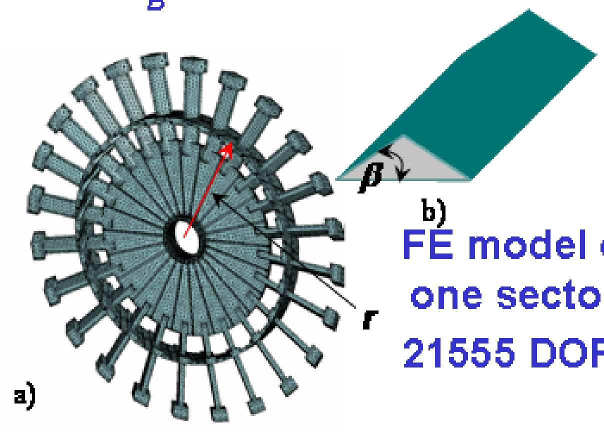


Stochastic analysis for forced response: when stochastic characteristics of parameters are available

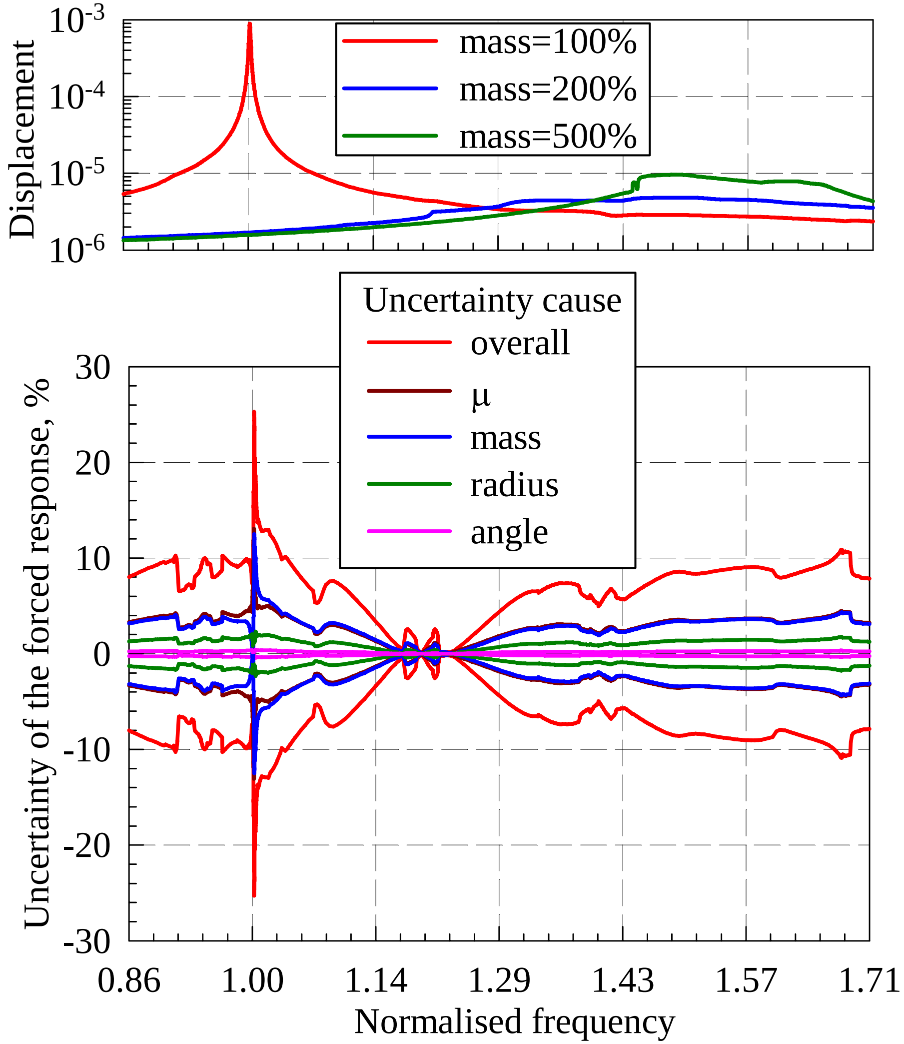


Example: analysis for ranges of uncertainty of the forced response

N_B=24



FE model of one sector: 21555 DOFs



Challenges

1) Validated constitutive equations describing forces at friction contacts (friction laws):

- for contacts in micro-slip, with small relative motion (bolted joints, flanges, blade-disc joints)
- for large high-energy rubbing motions and impacts (e.g. windmilling)
- for new materials (e.g. composites, rubber, polymers)

2) Friction contact parameters (e.g. friction and contact stiffness coefficients):

- prediction
- allowing for dependence and effects of operating conditions:

temperature, contact stresses, wear, oxidation, etc.