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Virtual Commissioning of Large Machines

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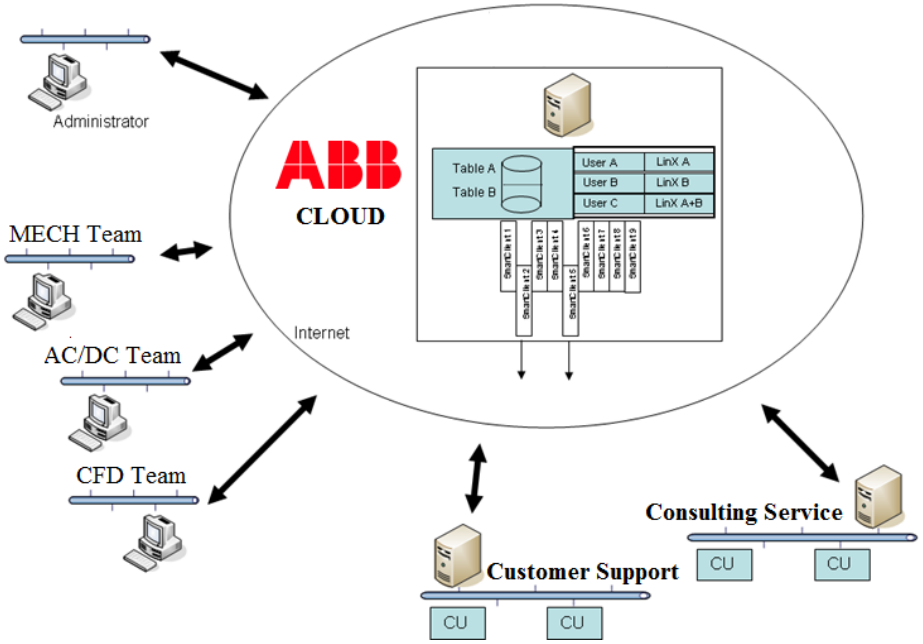
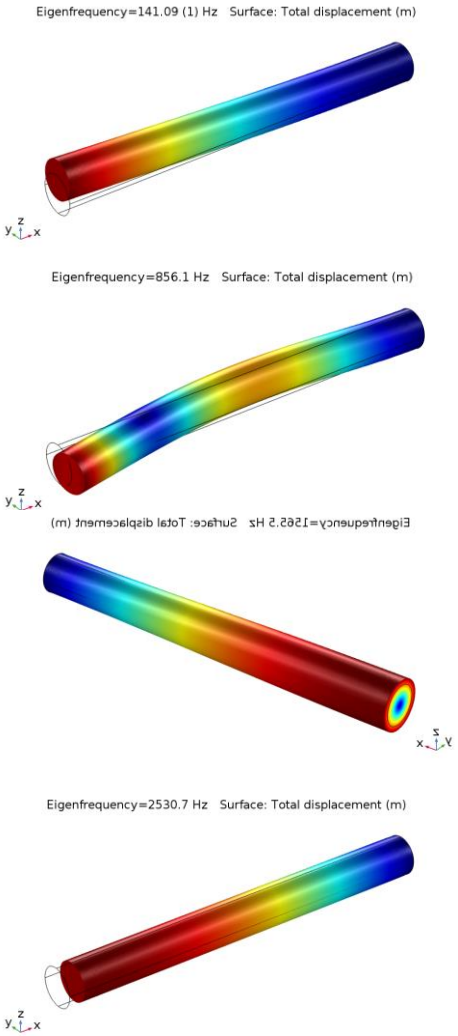
HELIOCENTRIC ARCHITECTURE



- Rotating machinery dynamics is an interesting combination of multi-physics, utilizing first principles of all mechanical engineering fundamental areas, solid dynamics, fluid-dynamics, electro-magnetism and heat transfer as well as the control.
- Application Builder combined with the COMSOL Server appears to be the right way of sharing the models and experience across the product development chain;
- The concept of virtual commissioning of large machines and drive-lines is attractive both to OEMs and to the customers. COMSOL Server provides a platform for creating and deploying applications and to back-up commissioning engineers by the expertise of the design team, making the installation process much faster and smoother.

It is the evolution not revolution; All good things take time (Jack Daniel)

Virtual Commissioning of Large Machines
Component Benchmark: Shafts



Fixed Free	**3.51**	**21.3**	**57.0**	**105.1**
	3.52	22.0	61.7	121.0
Fixed Fixed	21.6	56.2	103.5	159.6
	22.4	61.7	121.0	200.0
Fixed Hinged	15.1	46.8	92.2	147.7
	15.4	50.0	104.0	178.0
Free Free	21.8	57.6	107.0	-
	22.4	61.7	121.0	200.0

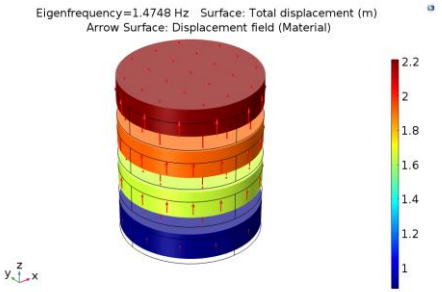
- Satisfactory accuracy is reached within the frequency range of several multiples of a nominal speed providing the use of sufficient number of elements (i.e. proper mesh);
- Also available 2-D models of Euler & Thimoshenko beams;
- COMSOL offers set of boundary conditions in terms of the fixed constrains or pre-defined displacements;

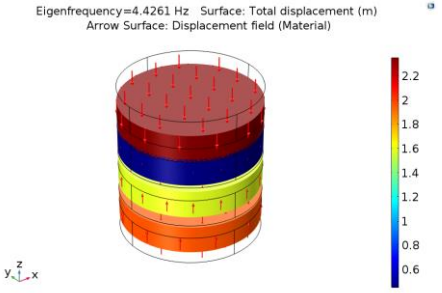
Virtual Commissioning of Large Machines
Component Benchmark: Couplings

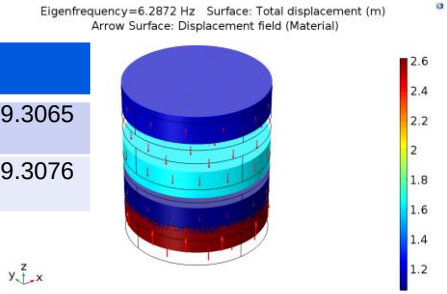
- COUPLING TYPES
  - Rigid coupling: often a spline connection locked tight on the shaft diameters;
  - Flexible coupling: a splined joint with crowned teeth and a crowned tip diameter allowing for large axial motion and modest amount of angular misalignment;
  - Distance piece with a joint on each side to accommodate wide range of misalignments.
- OEM DATA
  - Torsional stiffness;
  - Masses on each end with the center of gravity;
  - Bending stiffness in case of transmission of large power;
  - Damping ratios in terms of quality factors in case of a rubber coupling.

$$M = \begin{bmatrix} m & 0 & 0 & 0 \\ 0 & m & 0 & 0 \\ 0 & 0 & m & 0 \\ 0 & 0 & 0 & m \end{bmatrix}$$

$$K = \begin{bmatrix} 2*k & -k & 0 & 0 \\ -k & 3*k & -2*k & 0 \\ 0 & -2*k & 3*k & -k \\ 0 & 0 & -k & k \end{bmatrix}$$







	Frequency [Hz]			
COMSOL	1.4748	4.4261	6.2872	9.3065
MATLAB	1.4750	4.4266	6.2879	9.3076

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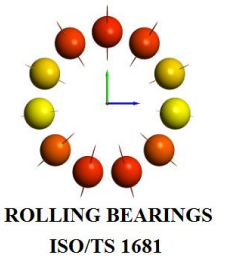
Component Benchmark: Rolling Element Bearings



- Rolling element bearings appear to be speed dependent.
- Due to centrifugal forces and gyroscopic effects of the elements, the contact angles changes are generating non-linear relations between forces and displacements.
- Sufficiently modelled by the 5x5 speed dependent stiffness and damping matrices.
- Further references: www.mesys.ch
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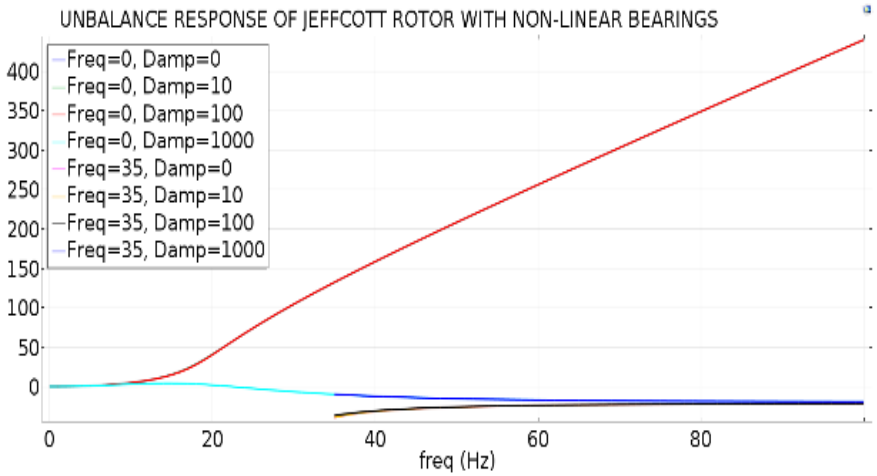
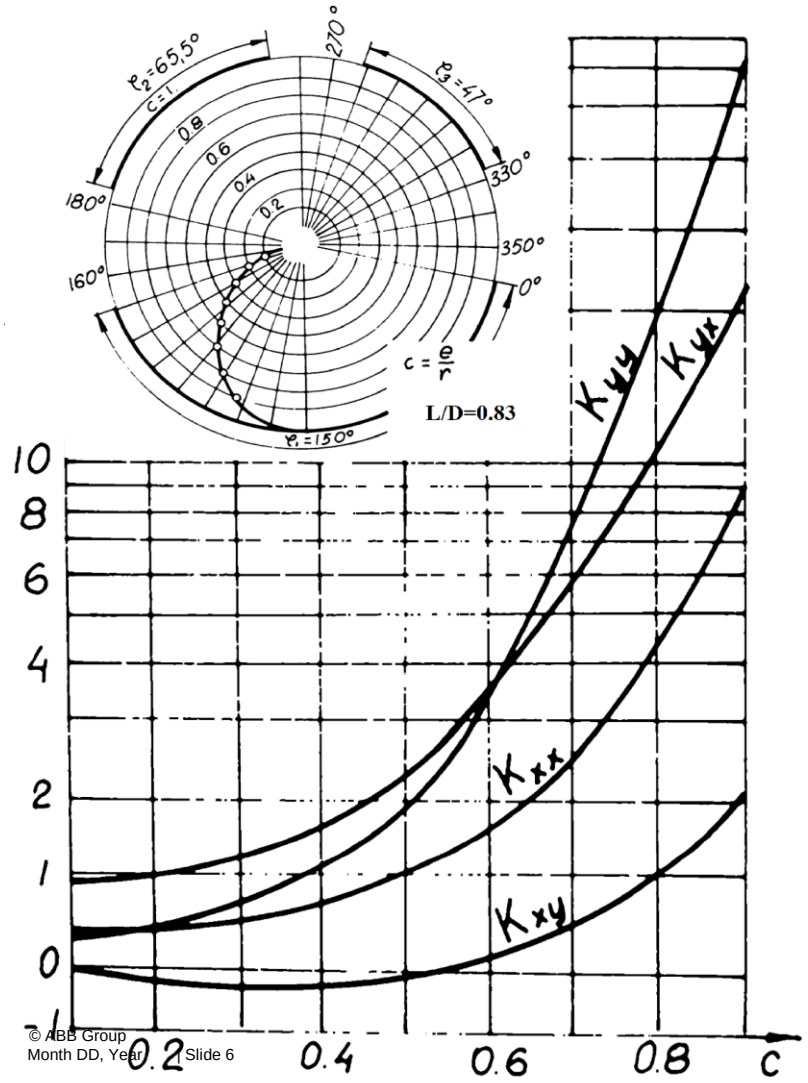


- Two steady state oscillations with the possibility of an amplitude jump between them.
- Additional parametric sweep of damping property showed that the solutions have converged to each other when sufficient amount of dissipation was introduced.

Virtual Commissioning of Large Machines
Fluid-Film Interaction: Oil-Film Bearings



- Anisotropic stiffness and damping characteristics of fluid-film represent the bearing behavior at steady-state equilibrium established under a static load such as gravity;
- ALP3T Algorithm: http://www.fvv-net.de/cms/upload/Projekte/2015-10_MTZ_1152_Journal_Bearings_Properties_Modelling_and_Verification_EN.pdf
- JSME Dbase of Journal Bearings available from Tsuneo Someya, ISBN-13: 978-3642525117

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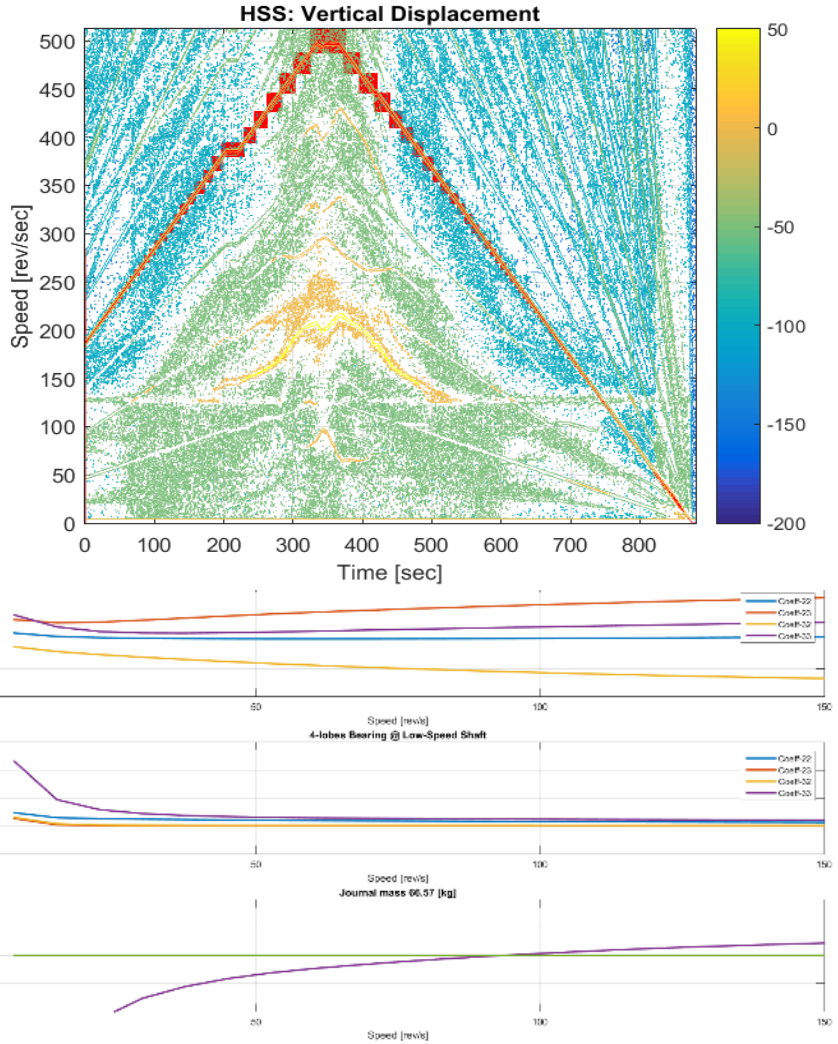
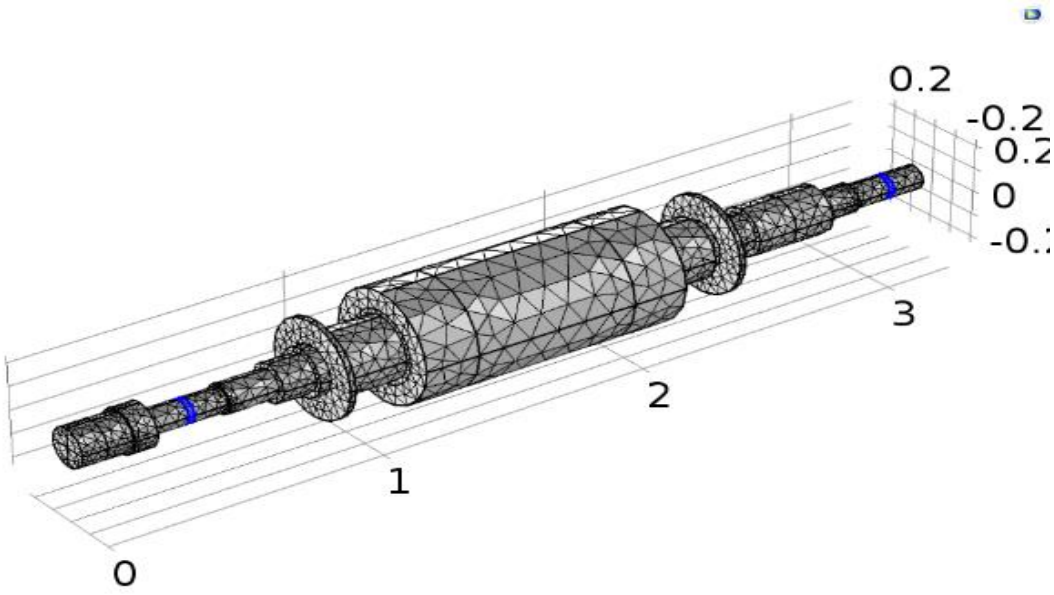
Fluid-Film Interaction: Oil-Film Bearings



- The journal is however pushed away from its equilibrium by dynamic forces, such as rotor unbalance causing it to whirl on an elliptical orbit.
- To justify the use of linearized bearing properties the orbit size needs to be relatively small in comparison to the bearing radial clearance.
- The linearized coefficients are then used to predict the stability thresholds or the bifurcation point beyond which the journal orbits nearly filling the entire bearing clearance and forming the limit cycles.

Virtual Commissioning of Large Machines
User Defined (PDE) Model

- COMSOL provides a unique feature of built-in library of partial differential equations (PDE) to be either arbitrarily connected to each other or to the one defined by the user;
  - Neumann conditions: specifying the surroundings effects and interactions. Those are often expressed in terms of forces, flux or current;
  - Dirichlet conditions: specifying the constraints resulting from the subsystems interaction at boundaries.



Displacements and velocities are accessible through the dependent variables:

- comp1.solid.uvw_rig1
- comp1.solid.uvw_rig1
- d(comp1.solid.uvw_rig1,TIME)
- d(comp1.solid.uvw_rig2,TIME)

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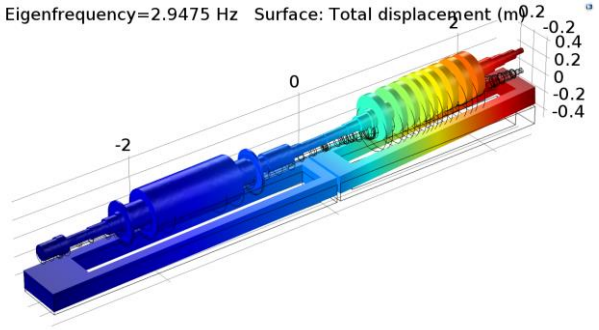
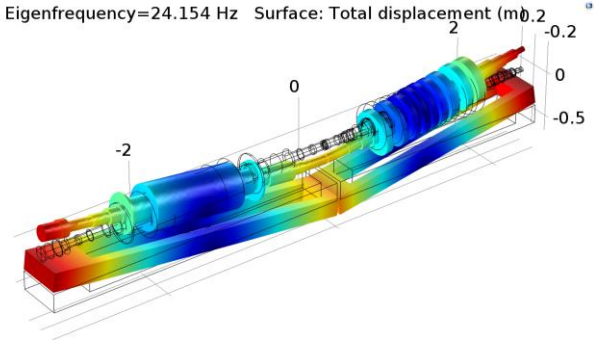
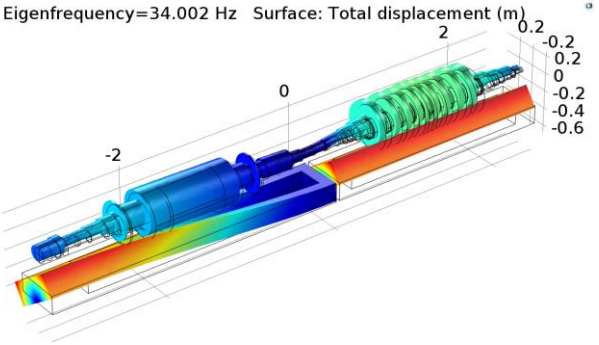
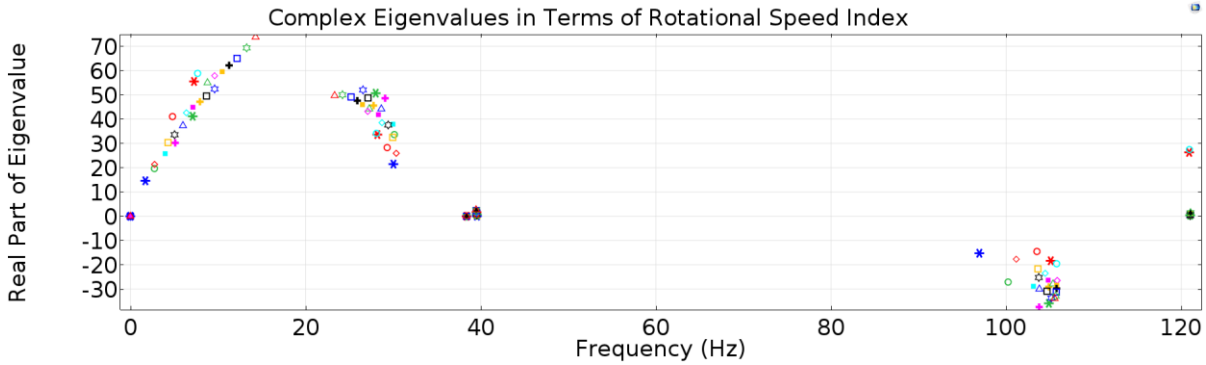
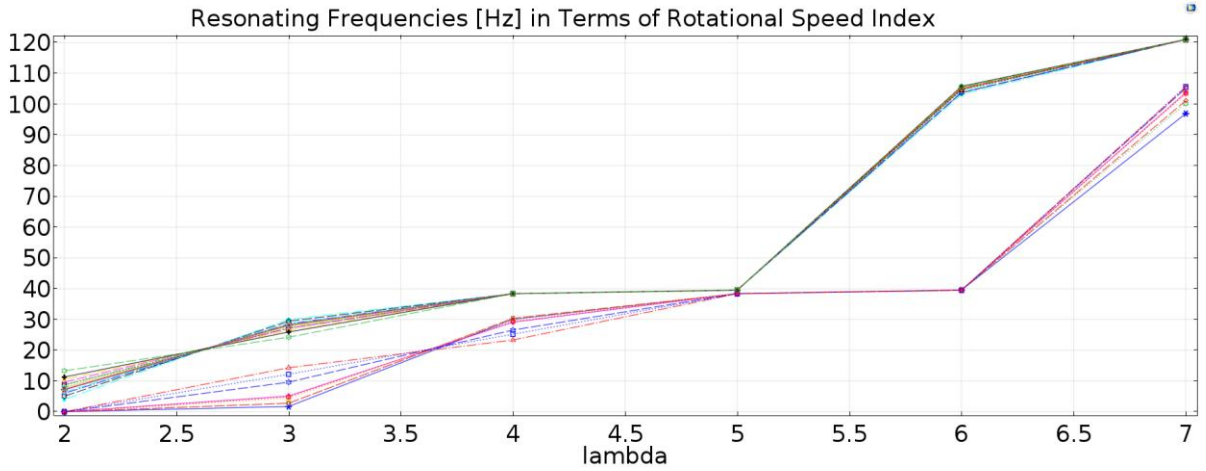
Motor-Compressor (MC)











Campbell diagram for salient pole synchronous motor

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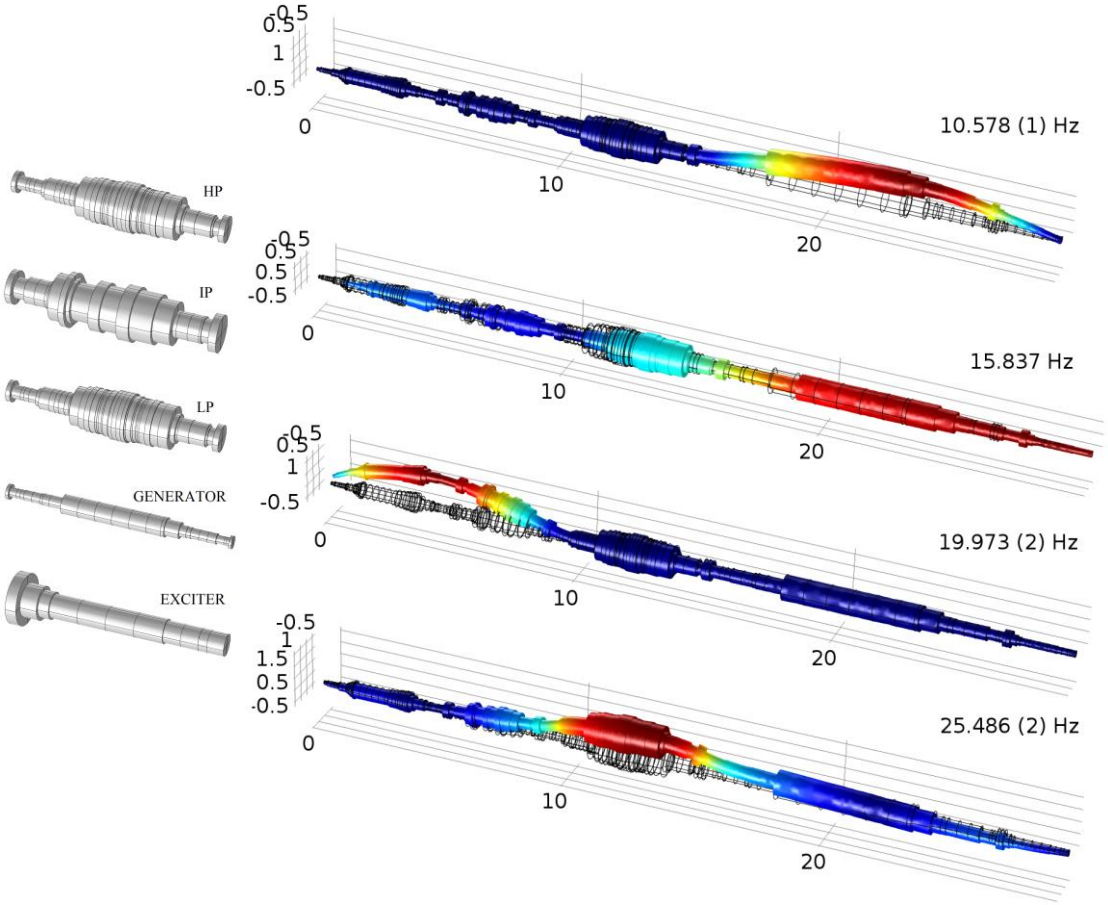
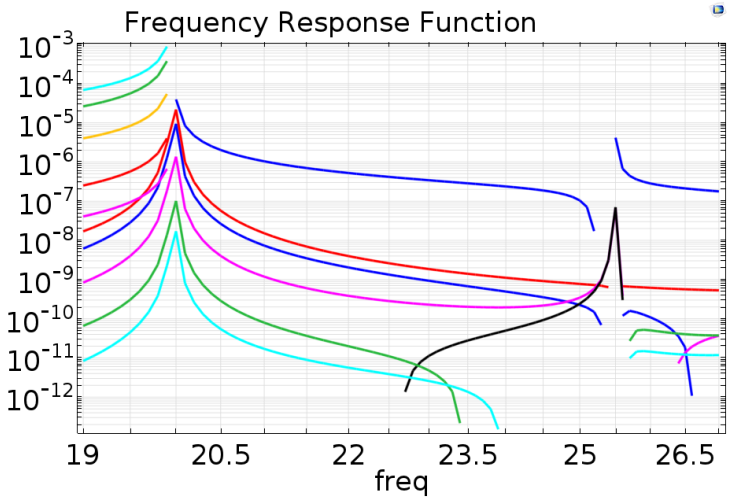
Turbo-Generator (TG)





MODAL CONDENSATION

$$[\Psi]^T[M][\Phi]\{\ddot{\eta}\}+[\Psi]^T[C][\Phi]\{\dot{\eta}\}+[\Psi]^T[K][\Phi]\{\eta\}=[\Psi]^T\{F\}$$

$$\{\ddot{\eta}\}+\mathrm{diag}[2\zeta\omega_n]\{\dot{\eta}\}+\mathrm{diag}[\omega_n^2]\{\eta\}=\{f\}$$

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