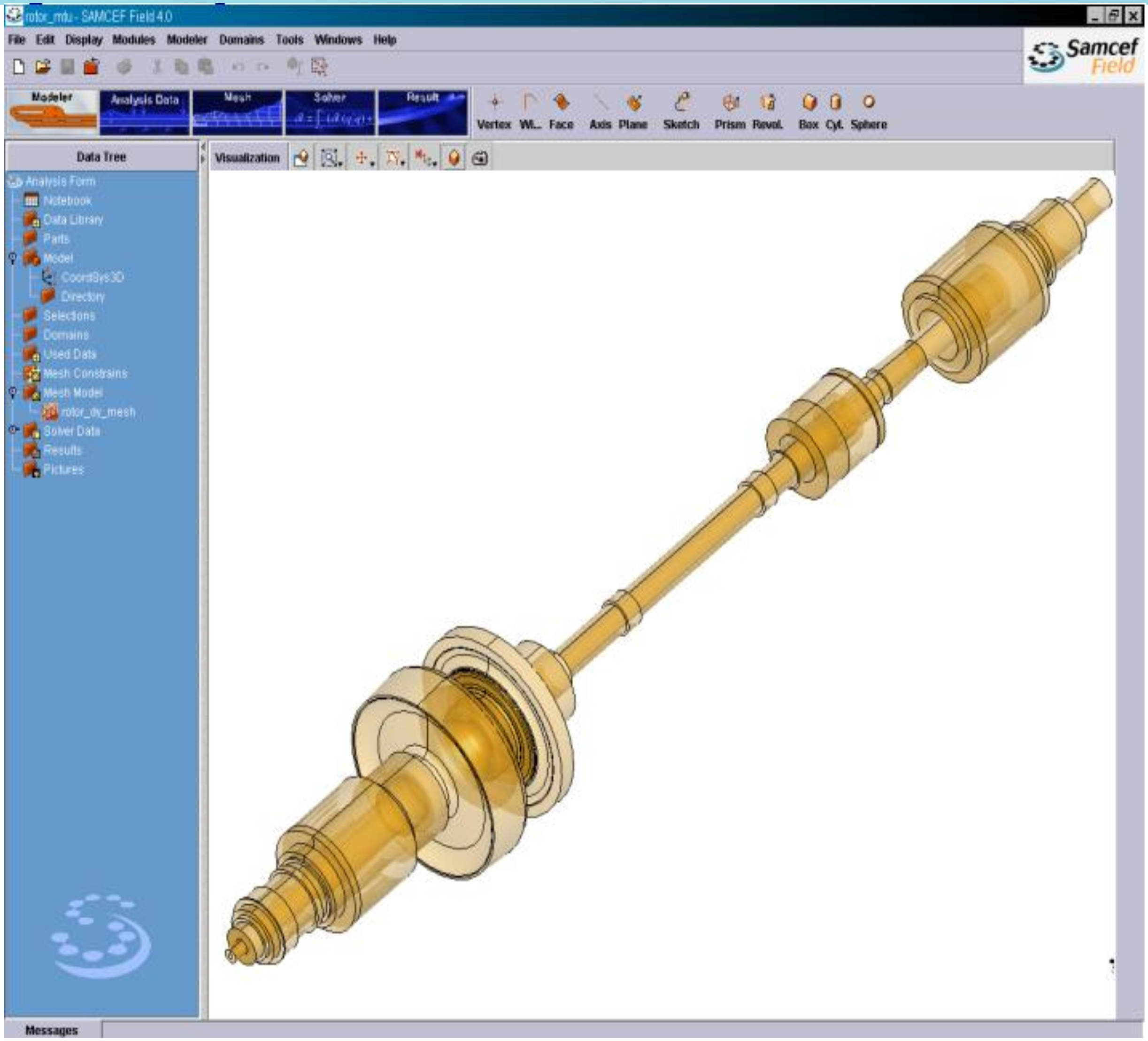
LMS Samtech

SAMCEF Rotors

SAMCEF Rotors is an integrated system for Rotor Dynamics Analyses including rotors, fixed parts and linking devices.

- SAMCEF Field pre- and post-processor with specific Rotor Dynamics driver
- ROTOR module for critical speed analyses and harmonic response
- ROTOR-T module for transient analyses
- DYNAM for Super-Element creation, recovery and ASEF for linear static analysis (from SAMCEF Linear)

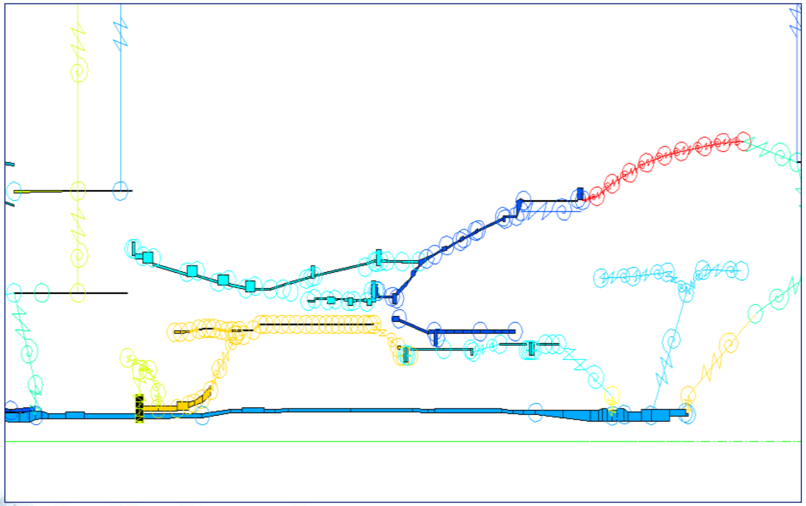


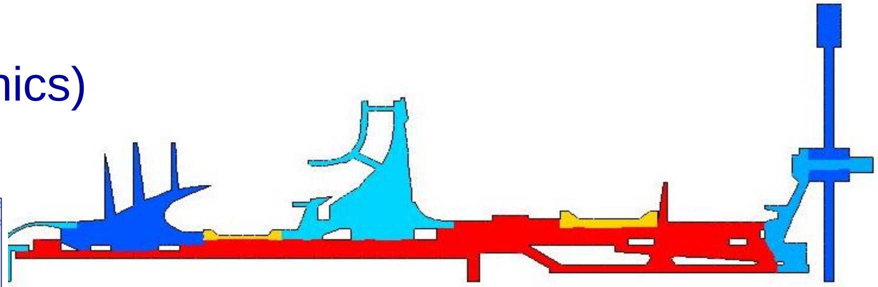
Rotor Modeling

One or several flexible rotors can be modeled with different rotational speeds and a free orientation in space.

❑ Available Models

- Inertial Frame approach including the gyroscopic effect
- Rotating Frame Approach (Coriolis and Centrifugal effects)
- Beam with rigid disks
- Axi-symmetrical (Fourier Multi Harmonics)
- 3-D model





❑ Damping

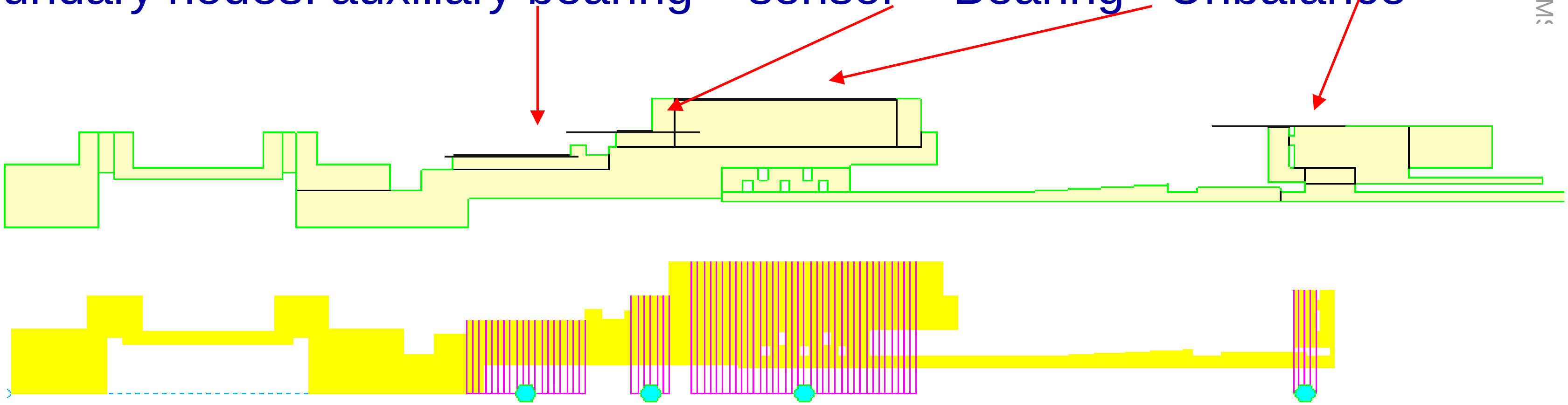
- Viscous proportional
- Variable
- Viscous circulatory forces in the inertial frame
- Hysteretical

Rotor Modeling: Fourier Multi Harmonic

Possibility to reduce the size of the model by Component Modes Synthesis (Super-Elements)

Example:

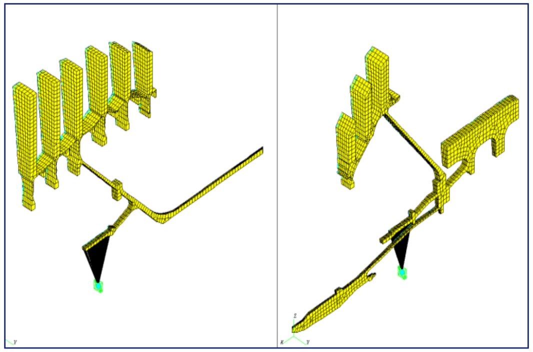
Boundary nodes: auxiliary bearing – sensor – Bearing - Unbalance



Idealization: Fourier links + mean element

Rotor Modeling: Cyclic Symmetry

- **3-D model**
  - **Inertial frame approach**
  - Cyclic symmetry
  - **Wave number 0 or 1**

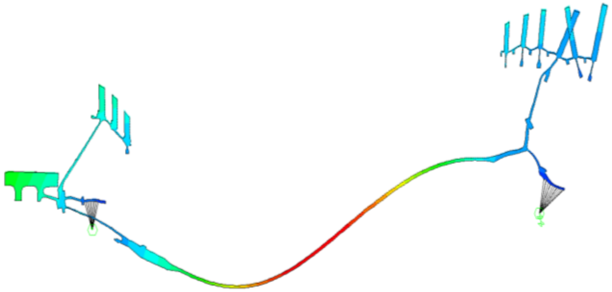


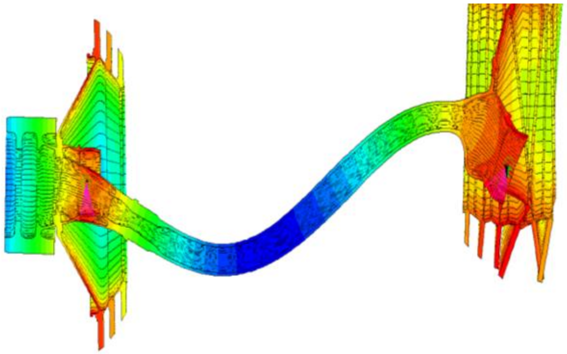
Wave propagation condition linking the left and right boundaries:

$$ {}^{l}\mathbf{q}^{(i)} = e^{\frac{2j\pi n}{N_i}} \; {}^{r}\mathbf{q}^{(i)} = e^{j\beta_i} \; {}^{r}\mathbf{q}^{(i)} $$

Example: identical critical speed prediction

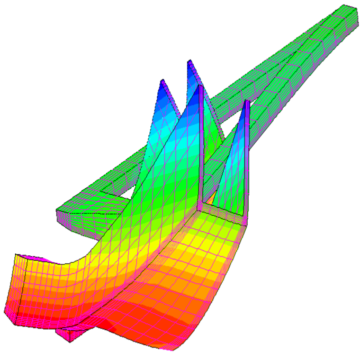
3rd forward 57.12 Hertz

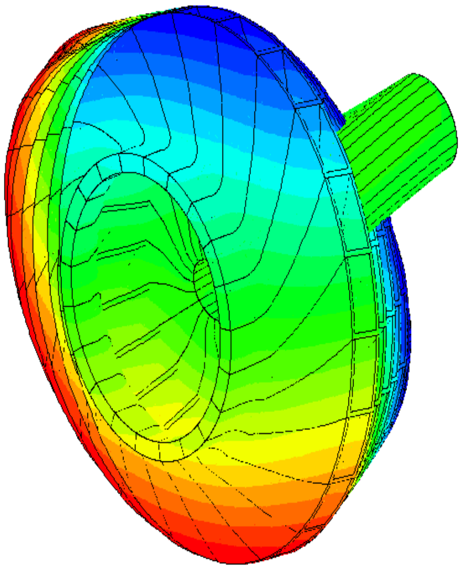




Rotor Modeling: Cyclic Symmetry

- **3-D model**
  - **Rotating frame approach**
  - No static parts
  - Cyclic symmetry or not





Wave propagation condition linking the left and right boundaries:

$$ {}^{l}\mathbf{q}^{(i)} = e^{\frac{2j\pi n}{N_i}}\; {}^{r}\mathbf{q}^{(i)} = e^{j\beta_i}\; {}^{r}\mathbf{q}^{(i)} $$

System of equations to be solved for one sector or the whole rotor:

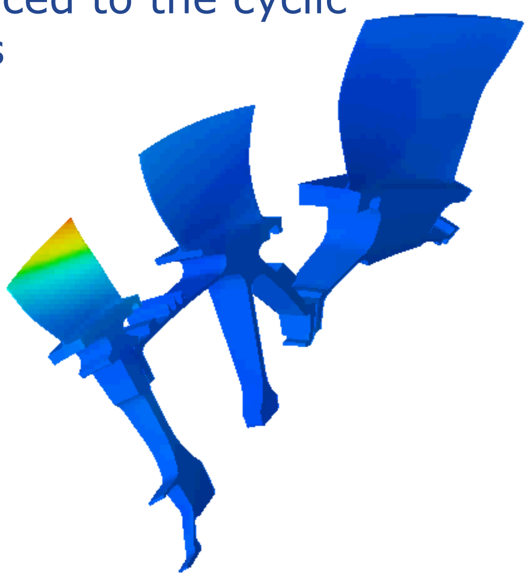
$$ \mathbf{f}(\mathbf{q}) - \Omega^2 \mathbf{N}\mathbf{q} = \mathbf{f}_C(\Omega^2) $$

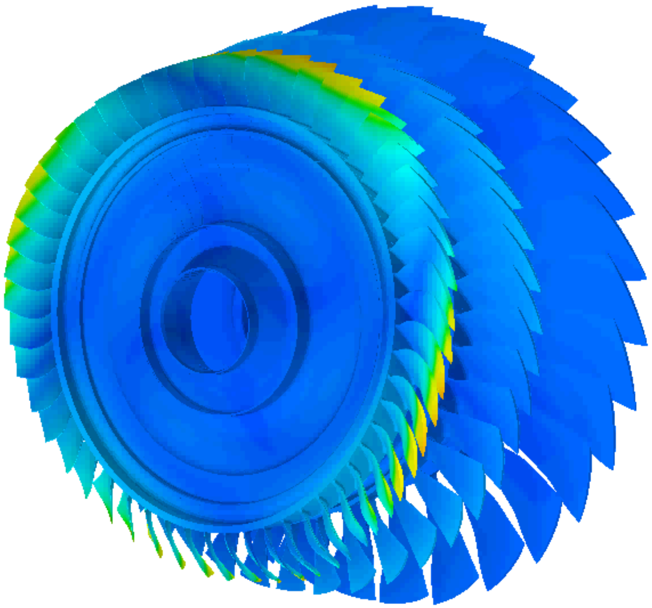
$$ \mathbf{M}\ddot{\mathbf{q}} + (\mathbf{B} + \Omega\mathbf{C})\dot{\mathbf{q}} + (\mathbf{K}_0 + \mathbf{K}_\sigma - \Omega^2\mathbf{N})\mathbf{q} = 0 $$

Rotor Modeling: Multi Stage Cyclic Symmetry

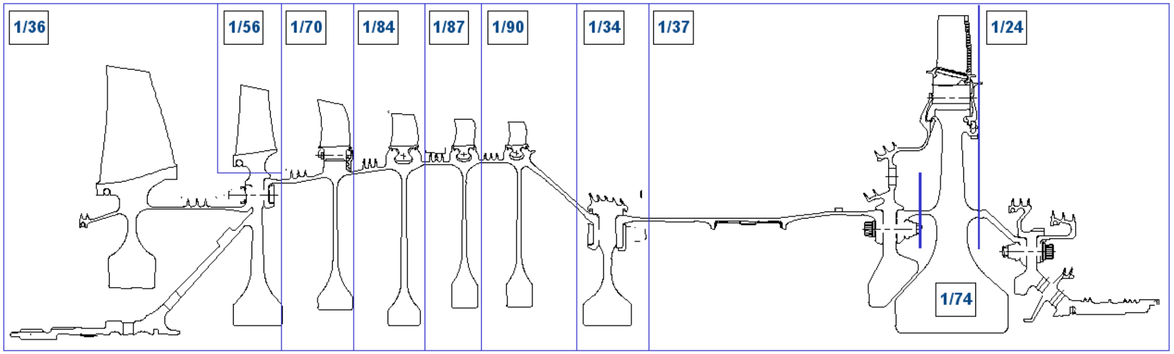
Principles:

- Each stage is modelled by one basic sector in cyclic coordinates
- The same wave number (engine order) is assumed for each stage (Approximation !) Additional Cyclic Fields per Stage may be used
- Continuity at inter-stage junction is first expressed in physical coordinates and then reduced to the cyclic ones

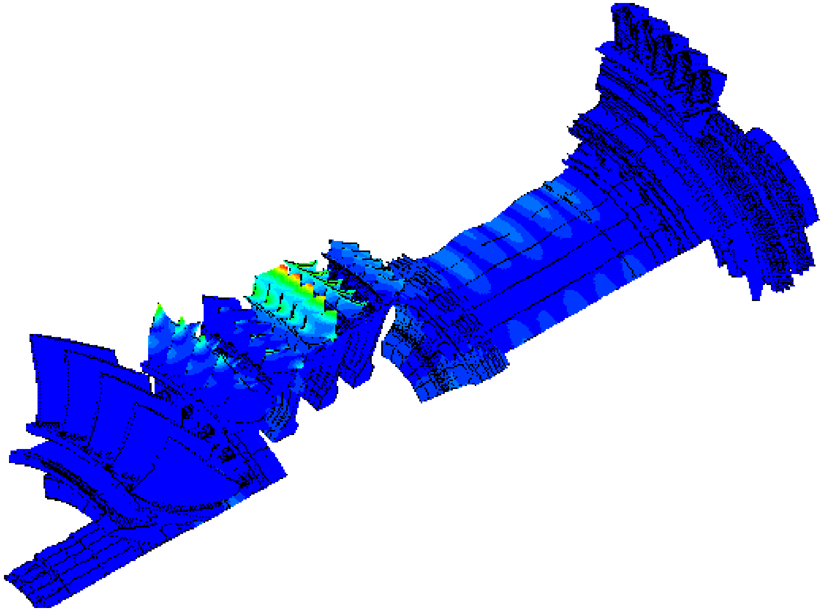




Rotor Modeling: Multi Stage Cyclic Symmetry



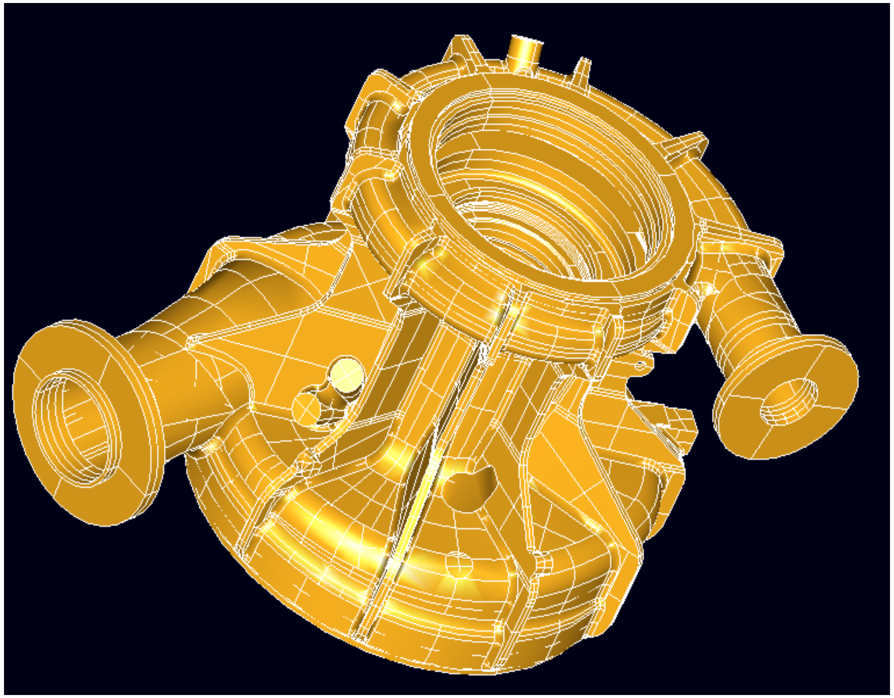
Nœuds				153 195
Eléments	Volume tétrahèdre		type 47	537 113
	Membranes triangle		type 57	153 820
	Eléments MAPP : - Collage STICK - ISD - SYC		type 162	14 858
	Masse concentrée		type 159	224
	Total			706 015
Nombre de degrés de liberté		Onde 0 Onde > 0		2 446 841 4 893 302



Stator Modeling:

The foundation or casing can be modeled with contribution to stiffness, mass and damping.

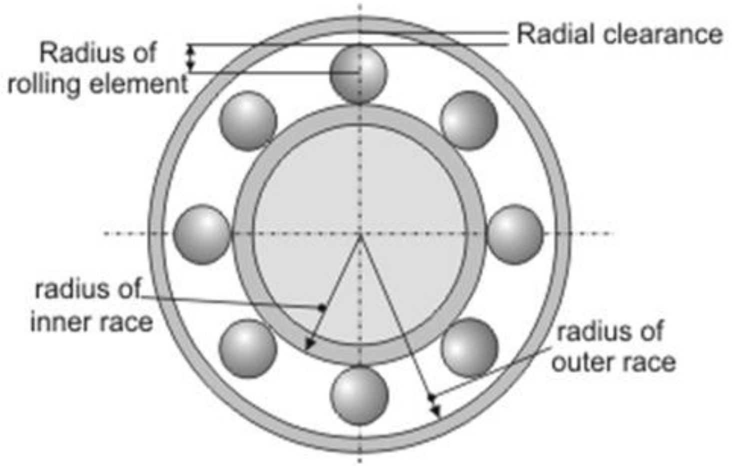
- Available Models
  - Inertial frame approach
  - Super-Elements
  - Full Finite Element library (rod, beam, bushing, rigid body, shell, volume and Fourier elements).



- Damping
  - Proportional
  - Viscous (constant or variable)
  - Hysteretical

Linking Devices

- Types of devices
  - Rolling element, journal or magnetic bearings
  - Seals
  - Squeeze film or solid-state dampers
  - Gears
  - Fluid interaction forces or rubbing

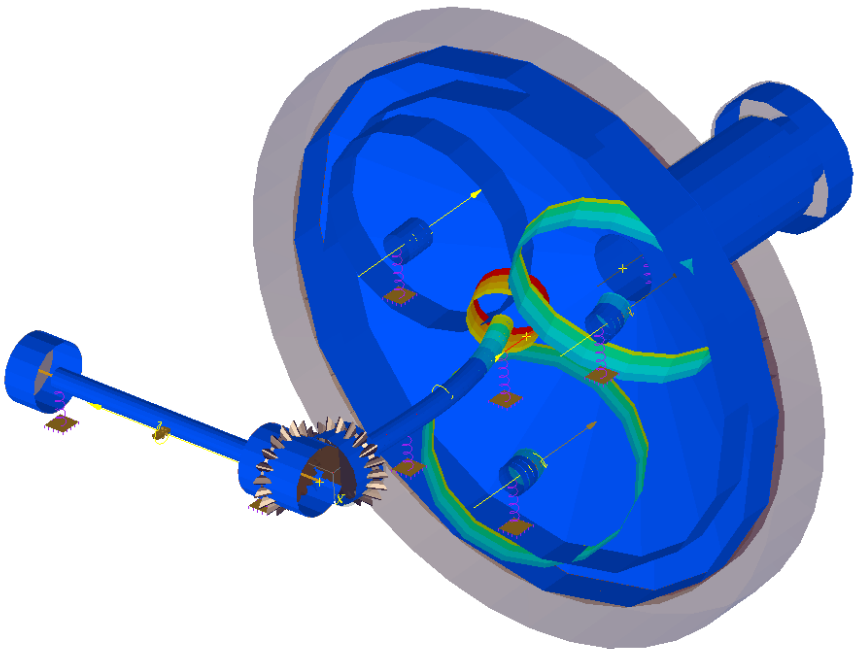


Schematic representation of a rolling element bearing

- Available joint library
  - Linear non symmetrical model
  - Transfer function (magnetic bearing)
  - Gear element
  - Bushing (rubbing, clearance)
  - Hydrodynamic journal bearing
  - Squeeze film damper

Linking Devices

- Gear element with pressure, toothing and conicity angles
- Coupling of bending, torsion and axial deformation



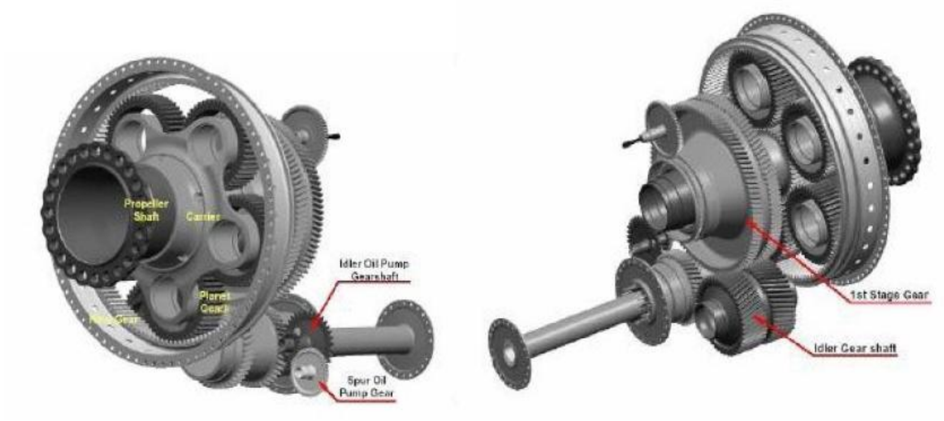
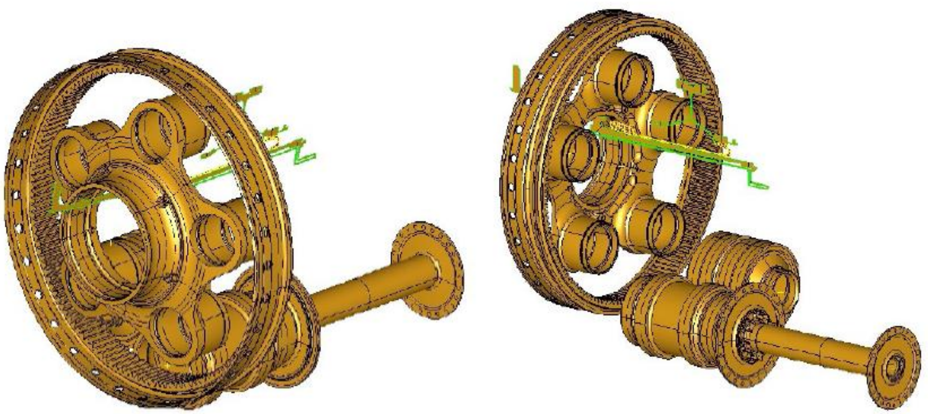


Fig. 2 – rotating parts

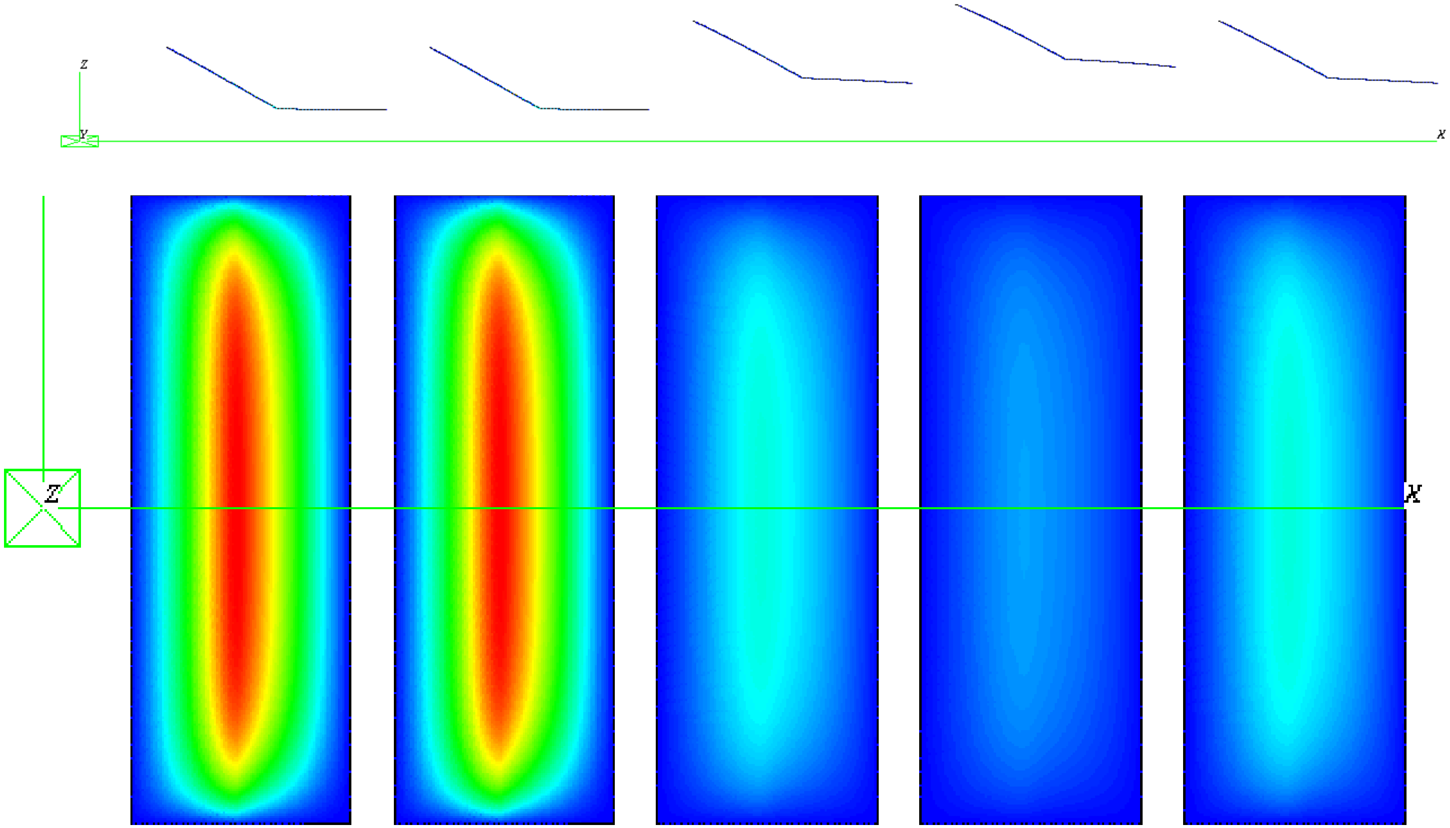


Linking Devices

Journal Bearings:

- ❑ Cylindrical
- ❑ Tilting pads
- ❑ Multi lobes

Tilting Pad Bearings: example 5 identical pads



Complex eigenvalue problem

$$\{\lambda^2 M + \lambda B(\Omega) + K(\Omega)\}\, q = 0$$

Methods

- *Sweeping*: within ranges of rotational frequencies where the complex eigen-values have to be computed.

→For large problems: sparse solver multi-frontal, Lanczos, subspace bi-iteration

- *Direct* : It gives the critical speeds as eigensolutions (undamped systems and constant stiffness only).

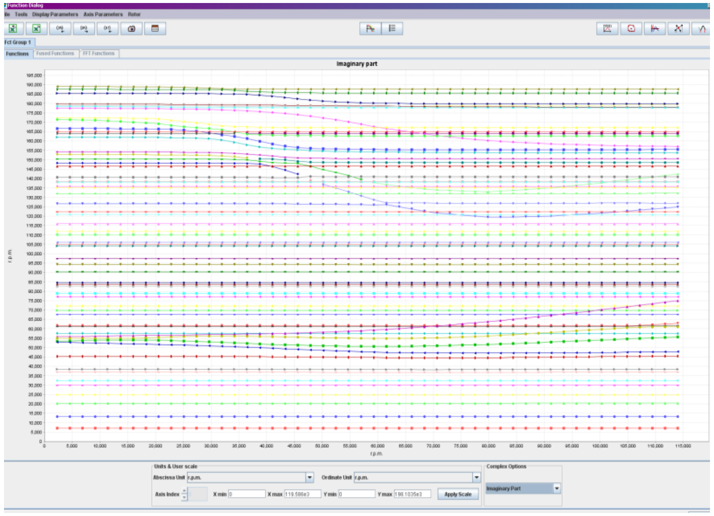
→Lanczos Method and Sparse Solver Available.

Results

- Complex eigenvalues (circular frequencies and damping coefficients), associated eigenvectors, generalized quantities and effective masses.
- Distribution of energies (kinetic energy, strain energy,gyroscopic and dissipation)
- Campbell's Diagram (Frequencies, Damping, Critical Damping and Root Locus)

Critical Speeds and Stability Analyses

❑ Campbell Diagram



- Critical speeds
- Damping
- Stability

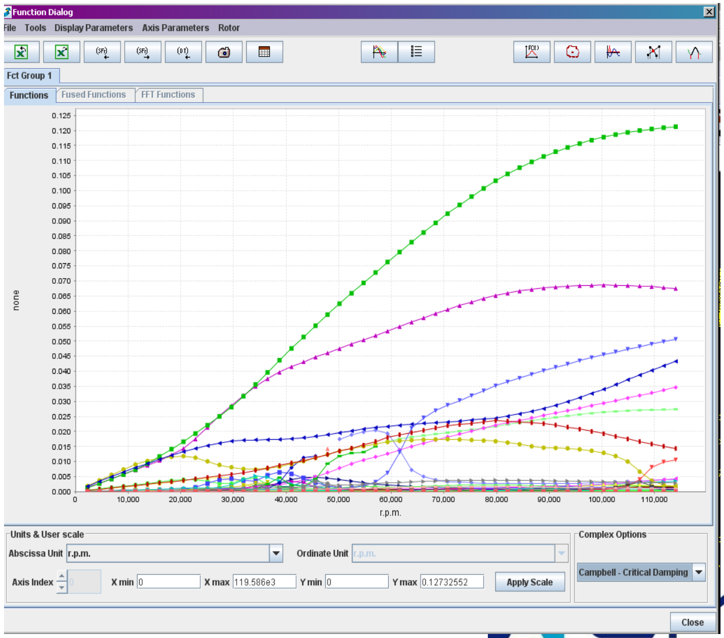
Critical speeds:

Critical speeds

Slope of the Critical Speed Line: 1

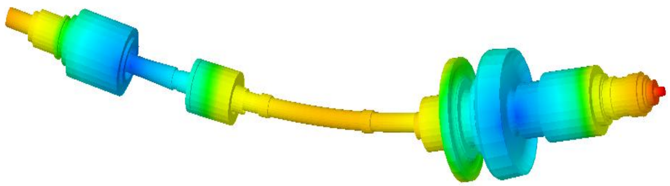
f(x)	X r.p.m.	Y r.p.m.
Complex Eigen Freque...	7048.50699848	7048.50699848
Complex Eigen Freque...	13219.49986019	13219.49986019
Complex Eigen Freque...	20349.81127619	20349.81127619
Complex Eigen Freque...	24834.83314292	24834.83314292
Complex Eigen Freque...	29861.19473281	29861.19473281
Complex Eigen Freque...	32175.13674137	32175.13674137
Complex Eigen Freque...	36884.90273573	36884.90273573
Complex Eigen Freque...	38400.47424875	38400.47424875
Complex Eigen Freque...	45011.74916846	45011.74916846
Complex Eigen Freque...	48631.58824464	48631.58824464
Complex Eigen Freque...	50892.30421238	50892.30421238
Complex Eigen Freque...	55011.8280051	55011.8280051
Complex Eigen Freque...	59322.24593919	59322.24593919
Complex Eigen Freque...	57494.60526507	57494.60526507
Complex Eigen Freque...	61190.59309758	61190.59309758
Complex Eigen Freque...	61731.78234056	61731.78234056
Complex Eigen Freque...	67568.41213876	67568.41213876
Complex Eigen Freque...	69775.72637862	69775.72637862
Complex Eigen Freque...	72062.92631661	72062.92631661
Complex Eigen Freque...	76971.68427407	76971.68427407
Complex Eigen Freque...	78830.72384155	78830.72384155
Complex Eigen Freque...	82437.92953462	82437.92953462
Complex Eigen Freque...	83664.26930884	83664.26930884
Complex Eigen Freque...	84490.56037485	84490.56037485
Complex Eigen Freque...	90357.94805135	90357.94805135
Complex Eigen Freque...	94179.66430441	94179.66430441
Complex Eigen Freque...	97294.02802375	97294.02802375
Complex Eigen Freque...	104074.13168788	104074.13168788
Complex Eigen Freque...	104808.08054493	104808.08054493
Complex Eigen Freque...	105953.78222414	105953.78222414
Complex Eigen Freque...	110128.76990824	110128.76990824

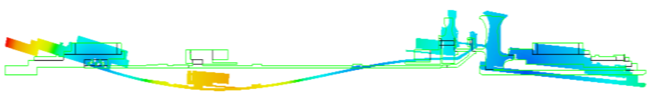
Close

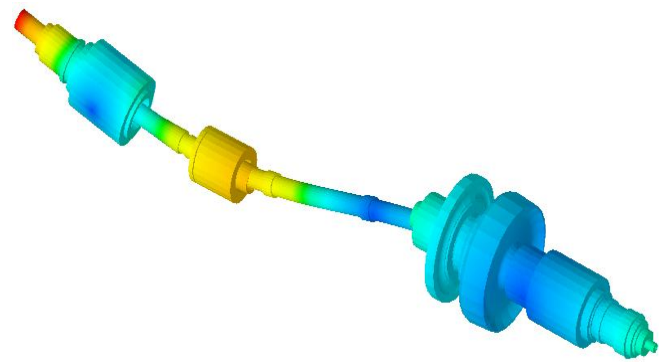


Critical Speeds and Stability Analyses

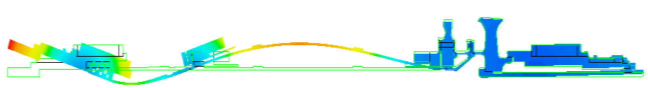
❑ Modes

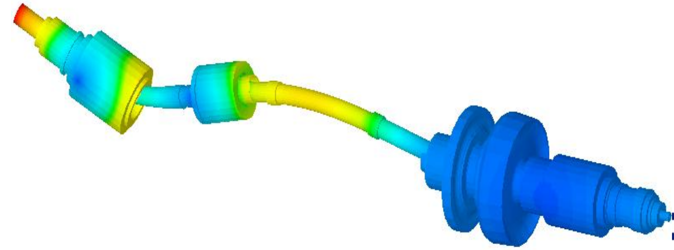






Mode	Test	Model
1	50.48 Hz	50.83 Hz
2	131.61Hz	130.74 Hz
3	351.59Hz	342.54 Hz





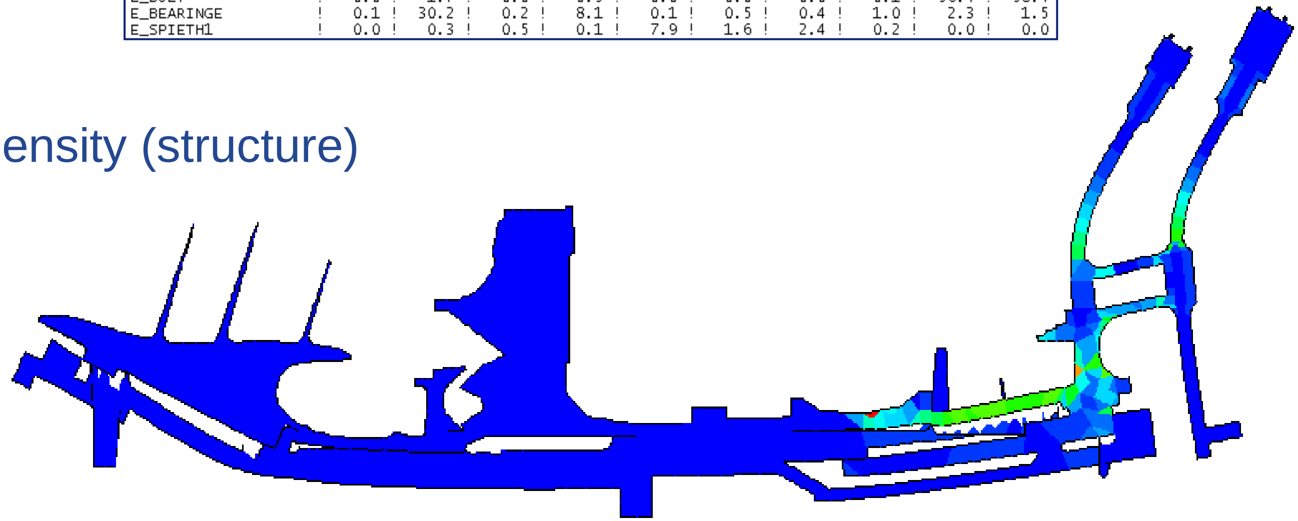
Critical Speeds and Stability Analyses

Energy Distribution per Mode

- Strain, kinetic, dissipation
- Percentages (linking devices)

Energies (in %)	Mode 1 2975.30 RPM		Mode 3 8014.84 RPM		Mode 5 22192.40 RPM		Mode 7 42185.79 RPM		Mode 9 62855.94 RPM	
	Energies		Energies		Energies		Energies		Energies	
Groups	Str.	Kin.	Str.	Kin.	Str.	Kin.	Str.	Kin.	Str.	Kin.
E_A	0.0	17.6	0.6	24.3	9.1	65.5	2.8	7.3	0.0	0.0
E_SHAFT	92.7	10.6	87.4	11.8	86.9	19.2	82.2	73.8	0.0	0.0
E_B	0.1	9.1	0.3	35.3	0.1	13.4	0.4	15.5	0.0	0.0
E_C	0.0	9.2	0.0	5.3	0.0	0.4	0.0	0.4	0.0	0.0
E_D	6.6	16.1	10.7	10.3	3.4	0.7	12.5	1.0	0.0	0.0
E_DISK	0.5	5.6	0.9	4.4	0.3	0.4	1.7	1.0	1.2	0.1
E_BOLT	0.0	1.7	0.0	0.5	0.0	0.0	0.0	0.1	96.4	98.4
E_BEARINGE	0.1	30.2	0.2	8.1	0.1	0.5	0.4	1.0	2.3	1.5
E_SPIETH1	0.0	0.3	0.5	0.1	7.9	1.6	2.4	0.2	0.0	0.0

- Density (structure)



Linear Harmonic Response

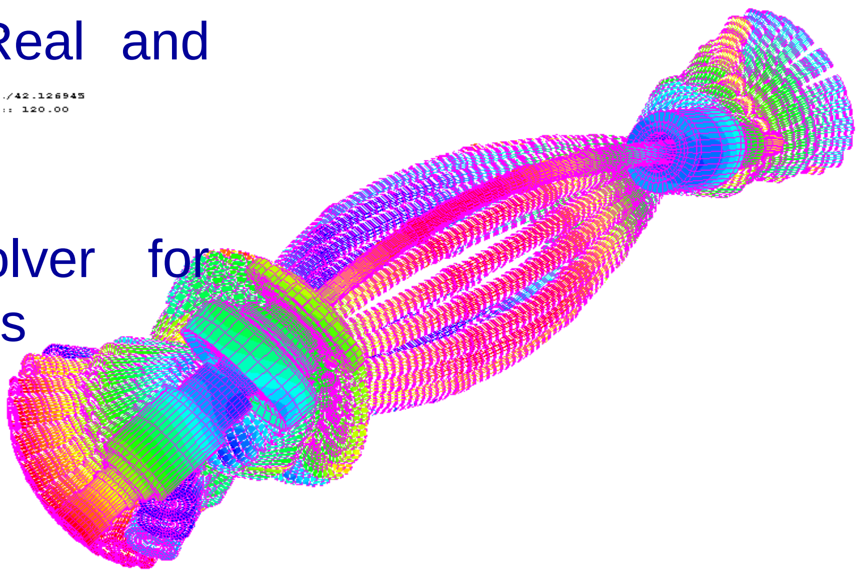
Loads

- Synchronous (unbalances)
- Non synchronous (gravity, rotating fluid force, pressures, maneuvres…)
- Force, Overall or local Acceleration, Displacement or Velocity

$$\{-\omega^2 M + i\omega B(\Omega) + K(\Omega\}\, q = g$$

Methods

- Projection on a Modal Basis (Real and Complex)
- Direct Complex Solver
- Frontal Method or Sparse Solver for Complex Non Symmetrical Systems



Non Linear Harmonic Response

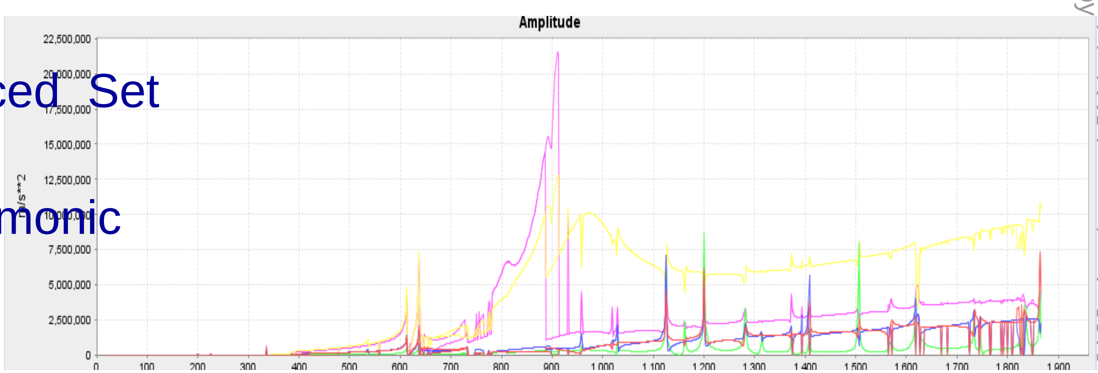
Non-linear terms as bushing, clearances, rubbing

Synchronous response (unbalances)

$$\{-\omega^2 M + i\omega B(\Omega) + K(\Omega)\}\, q + f(q) = g$$

Methods

- ❑ Direct Solver
- ❑ Newton-Raphson on a Reduced Set of DOF's
- ❑ Equivalent Linearization (Harmonic Balance)



Results for Harmonic Responses (Linear and Non Linear)

- ❑ *For a given Frequency*, drawing of Amplitude, Phase or Recombined Value (Displacements, Reactions and Stresses/Forces Moments) and Animation
- ❑ *Plots versus Frequency* of Amplitude & Phase of Displacements, Velocities, Accelerations, Forces, Reactions, Stresses and Moments

Transient Response

For Run-Up, Run-Down, Blade Losses (Unbalances) and Non Linear effects such as Clearances, squeeze-films, hydrodynamic bearings and rubbing

$$M\ddot{q} + B(\Omega)\,\dot{q} + K(\Omega, \dot{\Omega})\,q + f(q, \dot{q}, \Omega) = g(t)$$

With Local non-linearity, variable rotating speed, non-symmetrical Stiffness and Damping matrices

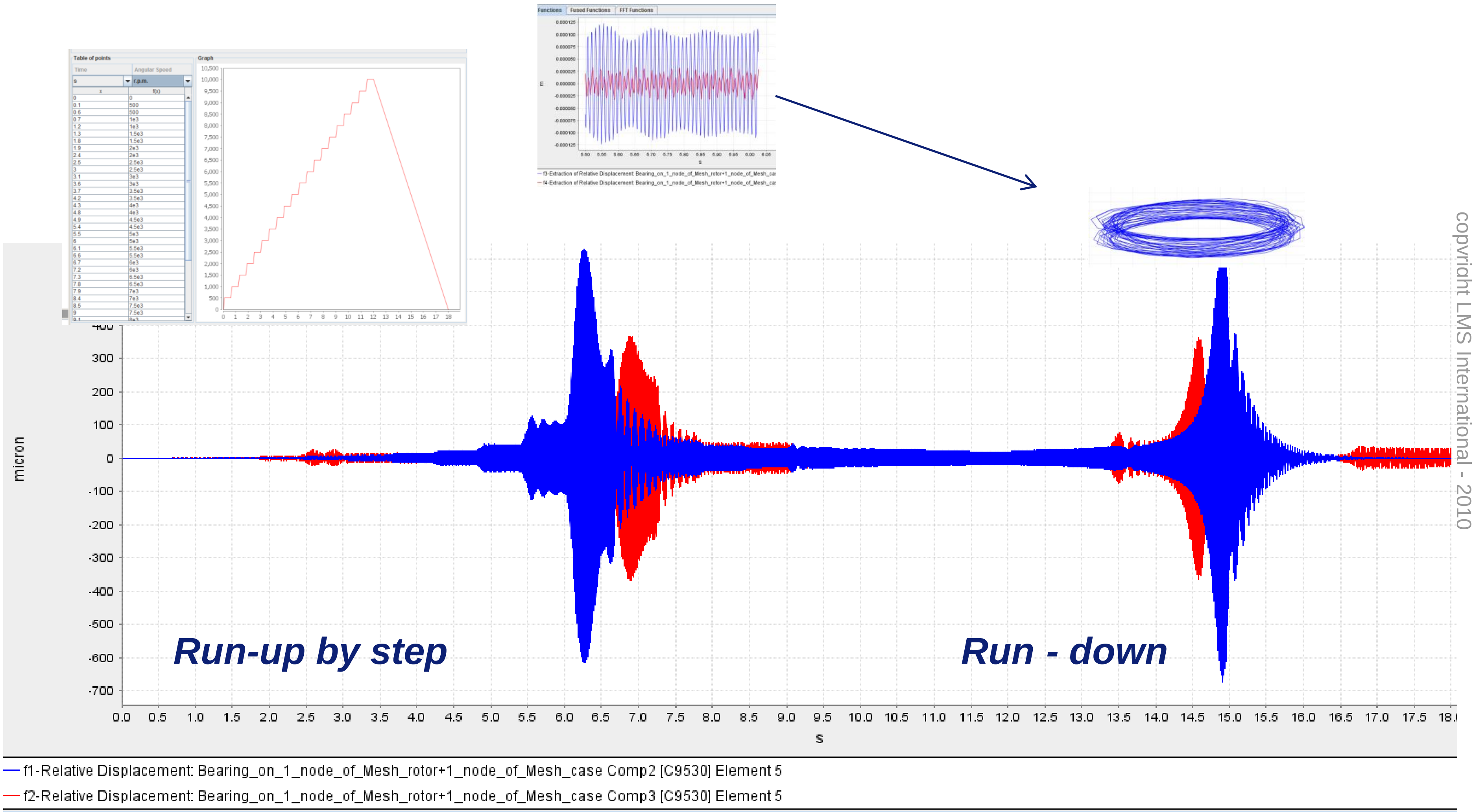
Loading

- External Applied Forces
- Overall Accelerations
- Local Accelerations

Initial Conditions

- Initially Statically Applied Forces
- Initial Stepwise Force
- Initial Dirac Impulse
- Initial Harmonic Force

Transient Response



Summary

SAMCEF Rotors

- **Accurate simulation of rotor dynamics,**

  - different level of models (beam, 2D, 3D, cyclic symmetry, …)
- **Applicable to very different domains** - - Aerospace (jet engines, turbo-pumps, …)

  - Energy (electricity production turbines)

  - Vehicles (boat, tanks, …)

  - Machines (centrifuge, fans, turbo chargers, …)
- **Complementary to LMS testing methods**
- **Various design situation**

  - critical speed

  - unbalance forced vibrations

  - run up, blade loss, .. transient analysis