

# Towards Rotordynamic Analysis with COMSOL Multiphysics

Martin Karlsson

Innovation by experience



Excerpt from the Proceedings of the 2012 COMSOL Conference in Boston.



# Background

- Rotordynamic analysis are carried out with special purpose rotordynamic codes
- Rotating equipment is supported by a structure and is physically coupled with it
- In special cases – a combined analysis might be needed
- Simulation driven design



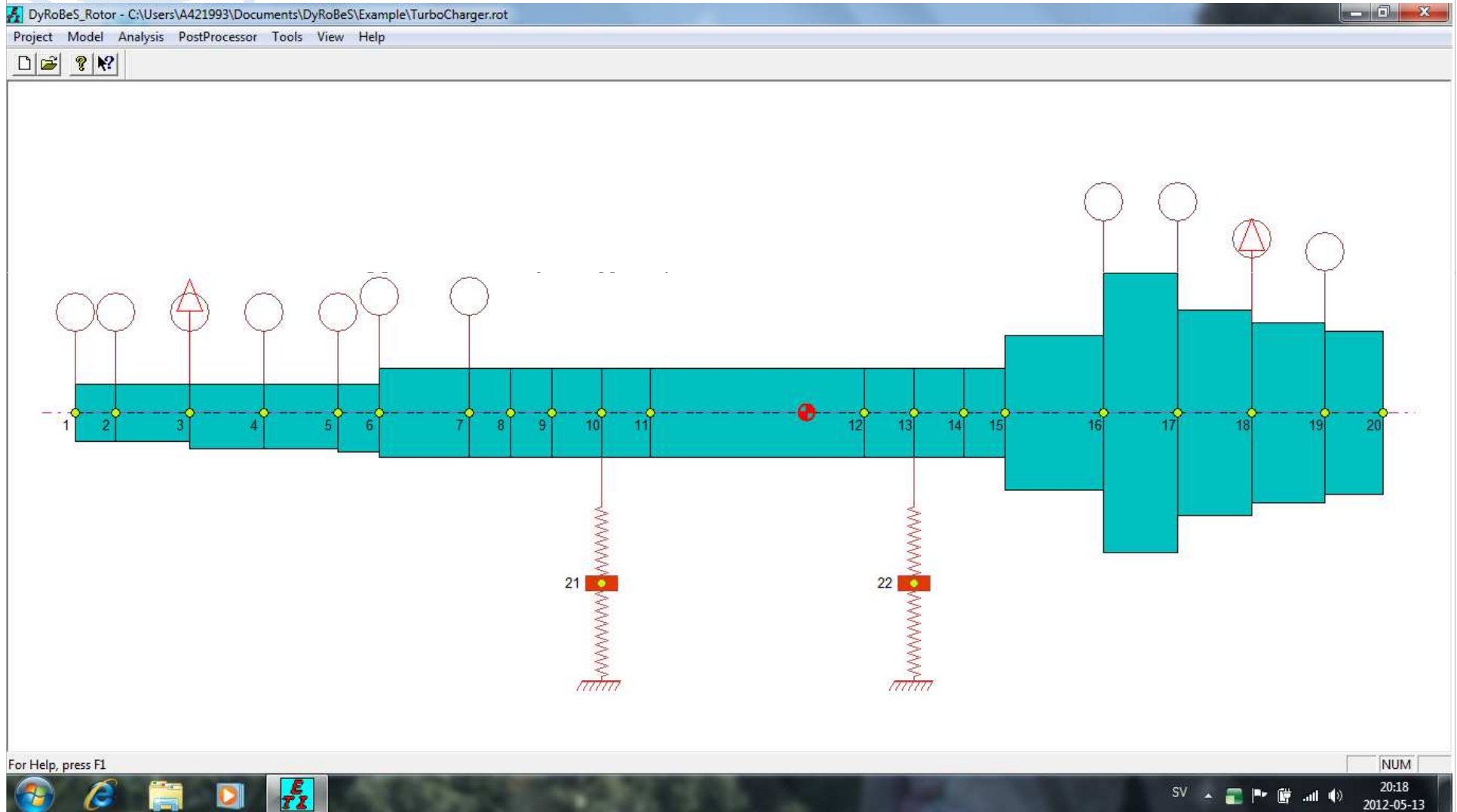


# Objective

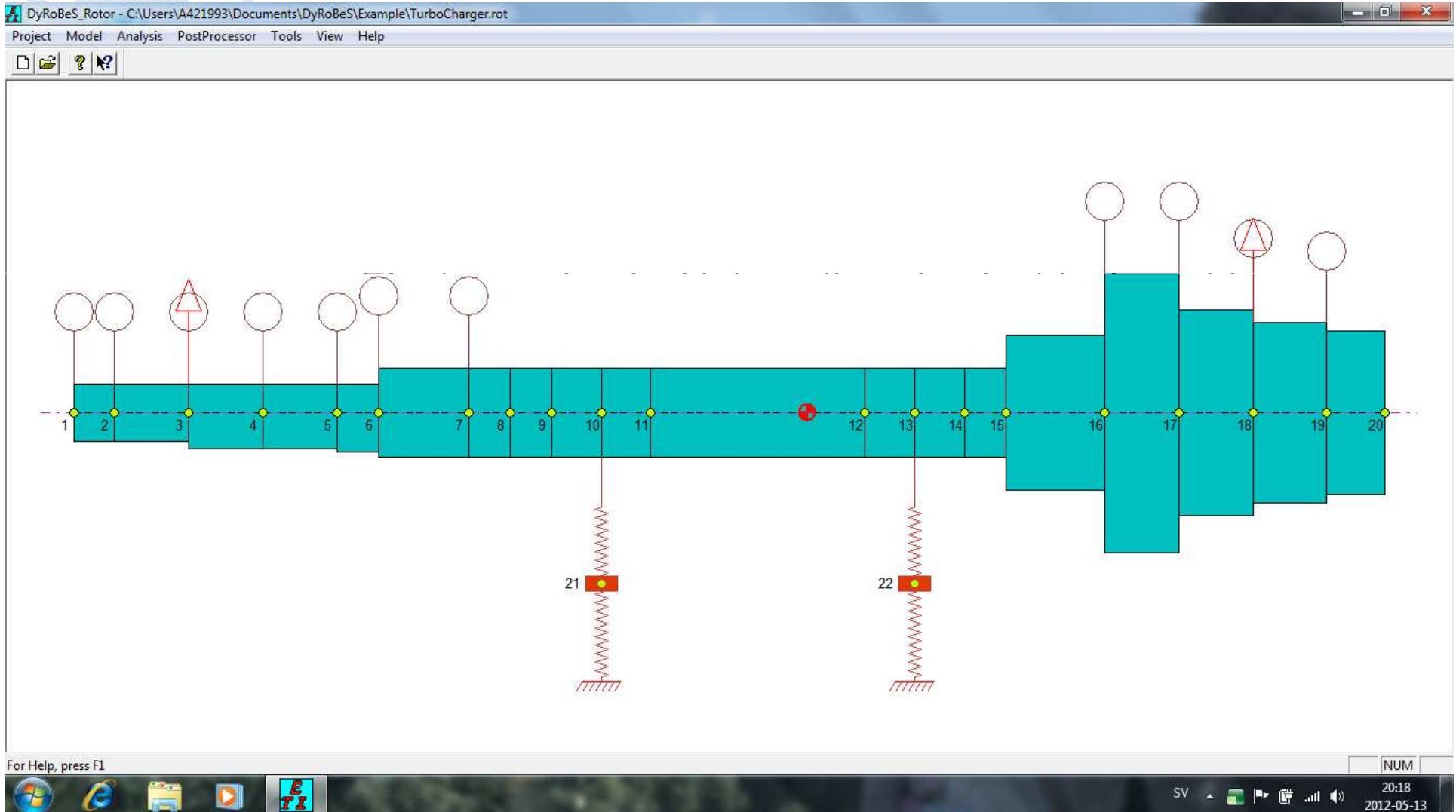
- What is needed to perform separate as well as combined rotordynamical and structural analysis of rotating equipment?



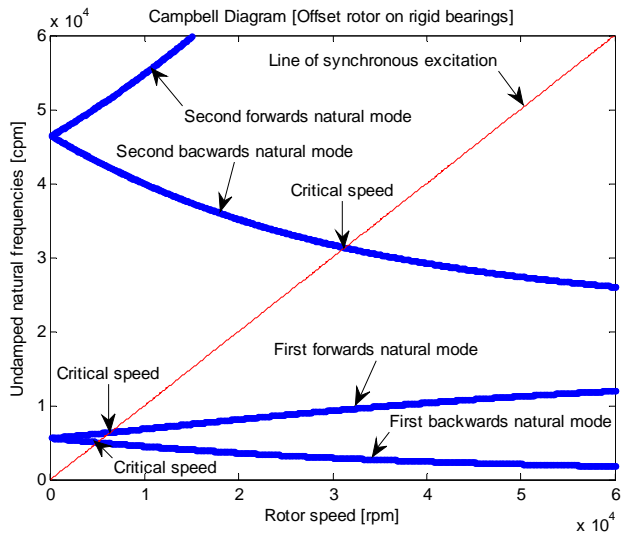
# Rotordynamical modelling



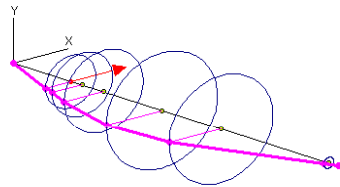
# Multiphysical interactions



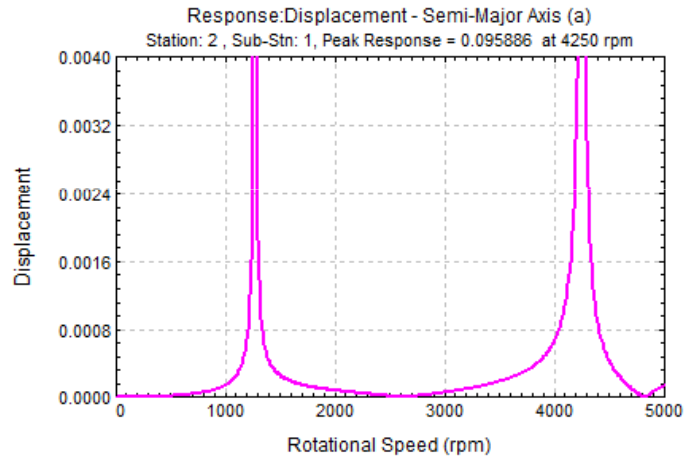
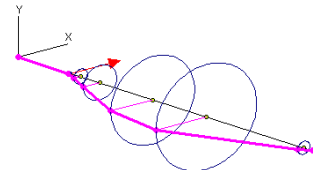
# Typical analysis



Shaft Response - due to shaft 1 excitation  
Rotor Speed = 1300 rpm, Response - FORWARD Precession  
Max Orbit at stn 5, substn 1, with a = 0.0040947, b = 0.0040947



Shaft Response - due to shaft 1 excitation  
Rotor Speed = 2500 rpm, Response - FORWARD Precession  
Max Orbit at stn 6, substn 1, with a = 0.00037377, b = 0.00037377





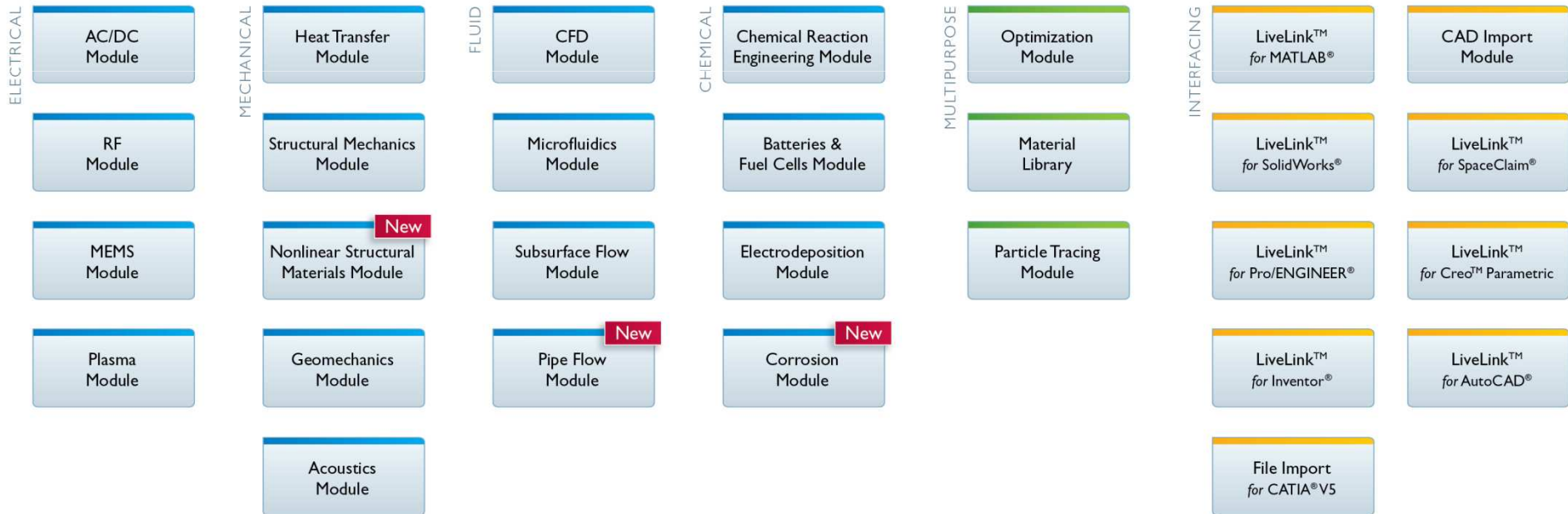
# Possible codes for combined analysis

- ABAQUS
- ANSYS
- NASTRAN
- COMSOL Multiphysics



# COMSOL Multiphysics

COMSOL Multiphysics®







# Implementation of rotordynamics

- Gyroscopic effect
- Rotordynamical coefficients
- Rotordynamical analysis by parametric sweep
- Calculations of rotordynamical coefficients

$$\bar{M}\ddot{\vec{x}} + (\bar{C} + \Omega\bar{G})\dot{\vec{x}} + \bar{K}\vec{x} = \vec{F}(t)$$



# Gyroscopic effect

3D-modelling of rotors.mph - COMSOL Multiphysics

File Edit View Options Help

Model Builder

- 3D-modelling of rotors.mph (root)
  - Global Definitions
  - Model 10.6 (mod1)
    - Definitions
    - Geometry
    - Materials
    - Beam (beam)
      - Elastic Material Model 1
      - Cross Section Data 1
      - Free 1
      - Initial Values 1
      - Cross Section Data 2
      - Prescribed Displacement/Rotation 11
      - Bearings
      - Gyroscopic load for shaft
      - Disk Mass Contribution
      - unbalance
      - Disk Gyroscope Contribution
      - Beam 2 (beam2)
      - Shell (shell)
      - Mesh 1
    - Eigenfrequency
    - Frequency Domain
    - Results
      - Data Sets
      - Views
      - Derived Values
      - Tables
      - Campbell Diagram
      - Modal Damping Ratio
      - Root Locus
      - Displacement
      - Phase

Settings

Model Library

26  
27  
28  
29  
30  
31  
32

Override and Contribution

Equation

Coordinate System Selection

Coordinate system:  
Global coordinate system

Force

Load type:  
Load defined as force per unit length

Edge load:

FL User defined

0	x	
0	y	N/m
0	z	

Moment

Moment edge load:

-0.5*beam.rho*pi*(sqrt(beam.area))^4*omega*thyt	x	
0.5*beam.rho*pi*(sqrt(beam.area))^4*omega*thxt	y	N
0	z	

Graphics

COMSOL MULTIPHYSICS

00-0.5 0 0.5 1 1.5

x  
y z

Messages Progress Log

COMSOL 4.2.1.110  
Opened file: 3D-modelling of rotors.mph

615 MB | 698 MB

SV 13:29  
2012-05-10

# Rotordynamic coefficients

The screenshot displays the COMSOL Multiphysics software interface for a 3D model titled "3D-modelling of rotors.mph". The interface is divided into several panes:

- Model Builder:** Shows a hierarchical tree of the model structure. The "Bearings" component is selected and highlighted in blue.
- Settings:** The "Point Load" settings are visible. The "Point Selection" is set to "Manual" with a list of selected points: 16 and 26. The "Coordinate System Selection" is set to "Global coordinate system". The "Force" section is expanded, showing a "User defined" point load with the following equations:

Equation	Variable	Unit
$-\left((u-u_2) \cdot l_{ox} + (v-v_2) \cdot l_{oy} + (beam.u_{tx} - beam2.u_{tx}) \cdot c_{ox} + (beam.u_{ty} - beam2.u_{ty}) \cdot c_{xy}\right)$	x	N
$-\left((v-v_2) \cdot l_{yy} + (u-u_2) \cdot l_{yx} + (beam.u_{ty} - beam2.u_{ty}) \cdot c_{yy} + (beam.u_{tx} - beam2.u_{tx}) \cdot c_{yx}\right)$	y	N
0	z	N
- Graphics:** Shows a 3D visualization of the shaft and bearing assembly. A coordinate system (x, y, z) is overlaid on the model. The shaft is shown with a mesh and a point load is applied at a specific location.
- Taskbar:** The Windows taskbar at the bottom shows the system tray with the time 13:34 and date 2012-05-10.



# Excitations

3D-modelling of rotors.mph - COMSOL Multiphysics

File Edit View Options Help

Model Builder Settings Model Library Graphics

3D-modelling of rotors.mph (root)

- Global Definitions
- Model 10.6 (mod1)
  - Definitions
  - Geometry
  - Materials
  - Beam (beam)
    - Elastic Material Model 1
    - Cross Section Data 1
    - Free 1
    - Initial Values 1
    - Cross Section Data 2
    - Prescribed Displacement/Rotation 11
    - Bearings
      - Gyroscopic load for shaft
      - Disk Mass Contribution
      - unbalance
      - Disk Gyroscope Contribution
  - Beam 2 (beam2)
  - Shell (shell)
  - Mesh 1
- Eigenfrequency
  - Parametric Sweep
  - Step 1: Eigenfrequency
  - Solver Configurations
  - Job Configurations
- Frequency Domain
  - Step 1: Frequency Domain
  - Solver Configurations
  - Job Configurations
- Results
  - Data Sets
  - Views

Point Load

Point Selection

Selection: Manual

22

Override and Contribution

Equation

Coordinate System Selection

Coordinate system: Global coordinate system

Force

Point load: User defined

$M_e \cdot e \cdot \omega^2$	x	
$M_e \cdot e \cdot \omega^2$	y	N
	z	

Moment

Point load:

0 x

Graphics

0 -0.2 0.5 1 1.5

Messages Progress Log

COMSOL 4.2.1.110  
Opened file: 3D-modelling of rotors.mph

616 MB | 699 MB

13:49  
2012-05-10

# Solvers

The screenshot displays the COMSOL Multiphysics software interface for a 3D model of a rotor. The main window is titled "3D-modelling of rotors.mph - COMSOL Multiphysics". The interface is divided into several panes:

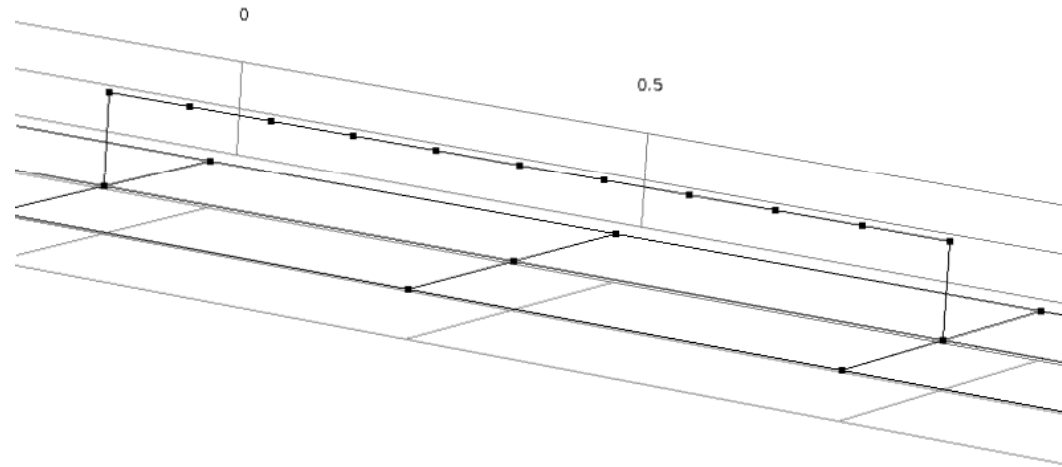
- Model Builder:** Shows a hierarchical tree of the model structure. The "Parametric Sweep" node is selected under the "Eigenfrequency" study.
- Settings:** The "Parametric Sweep" settings are visible. Under "Study Settings", the parameter name is "Fr" and the values are "1.00E+00 1.33E+00 1.66E+00 1.99E+00 2.32E+00". Under "Output While Solving", the "Plot" checkbox is checked, and the "Plot group" is set to "Campbell Diagram". The "Probes" list includes "Eigenfrequency", "Modal Damping Ratio", "phaseX", and "phaseY". The "Accumulated probe table" checkbox is also checked.
- Graphics:** Shows a 3D view of the rotor model with a coordinate system (x, y, z). The rotor is a long, thin cylindrical component with a central shaft. The x-axis is labeled with values 0, 0.5, 1, and 1.5.
- Messages/Progress/Log:** The bottom right pane shows the message "COMSOL 4.2.1.110" and "Opened file: 3D-modelling of rotors.mph".

The system tray at the bottom of the screen shows the date and time as "13:48" and "2012-05-10".



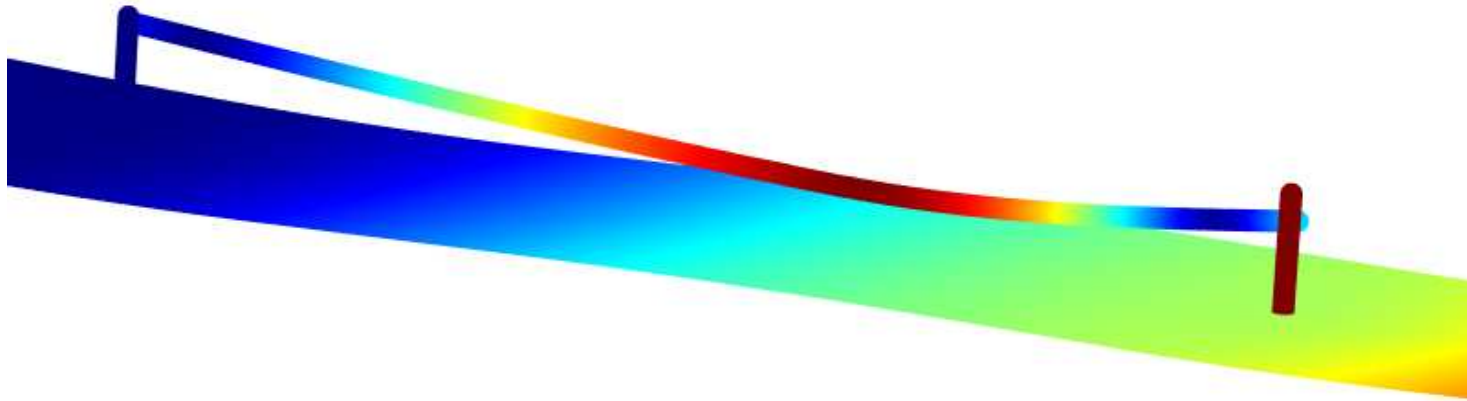
# Couple a rotor model to a structural model

COMSOL  
MULTIPHYSICS

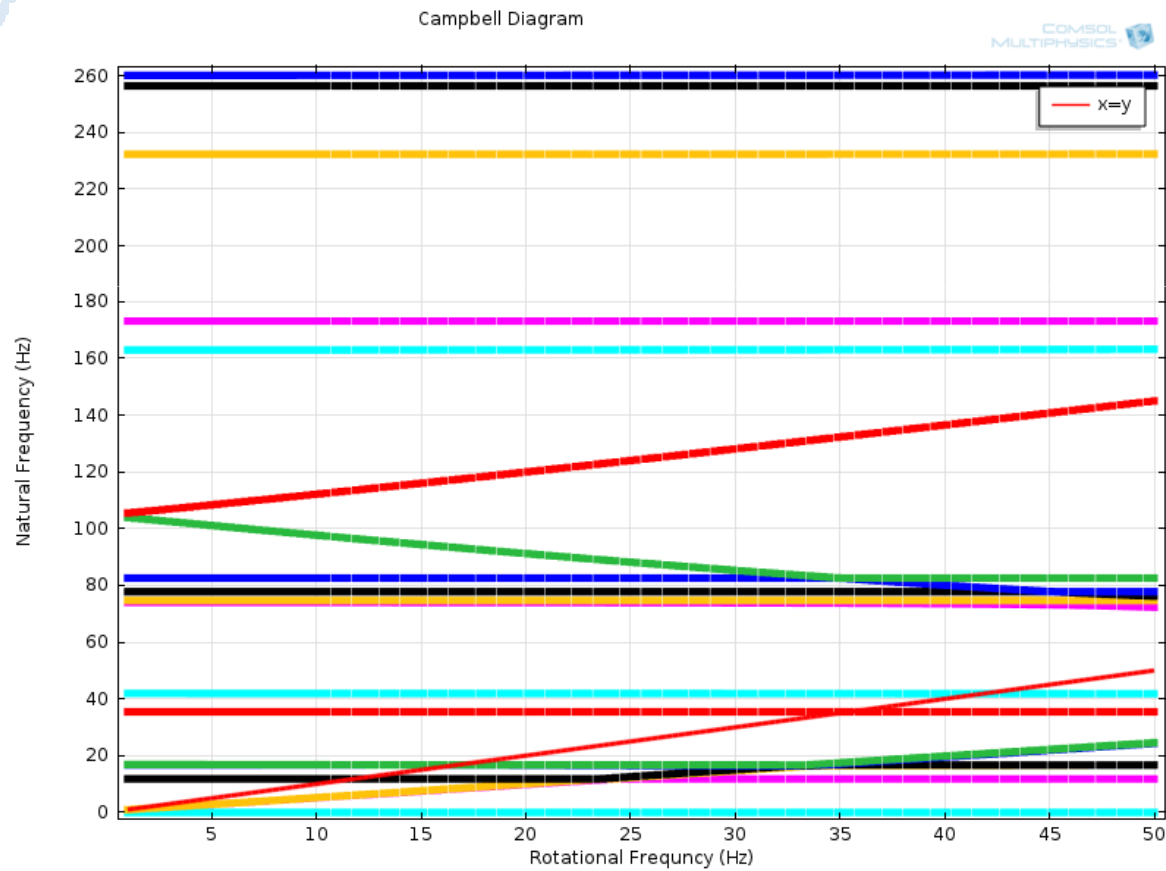




# Example of results – foundation – support – rotor mode shape

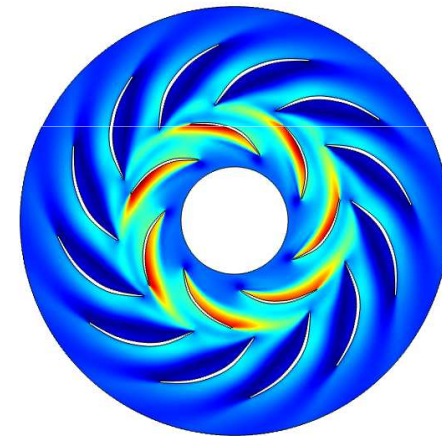
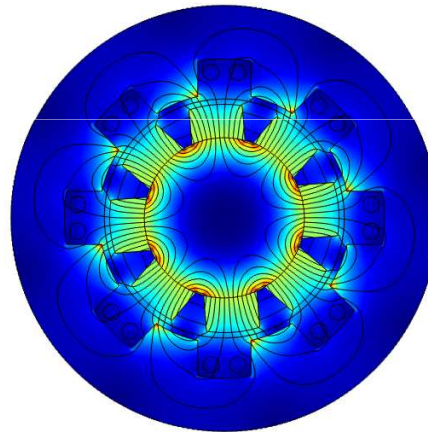
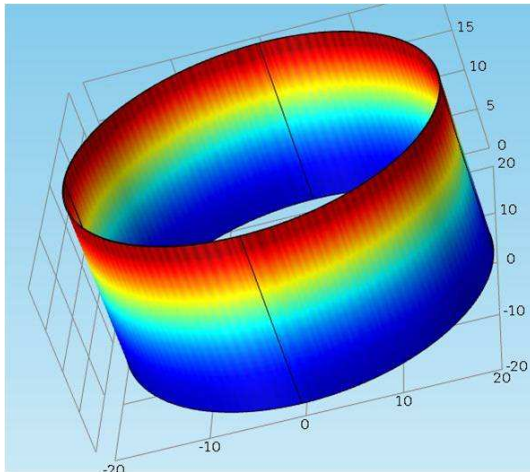


# Example of results - Campbell plot





# Calculation of rotordynamical coefficients





# Conclusions

- Possible to design an engineering tool in order to carry out coupled rotordynamical and structural analysis
- Possible to identify rotordynamical coefficients using numerical methods
- Further implementation needed for a complete 3D-rotordynamical analysis

