Analysis of a Friction Damper System for the New Cryogenic Upper Stage ESC-A of Ariane 5 with Pro/MECHANICA

1st Pro/MECHANICA User's Conference at DENC AG

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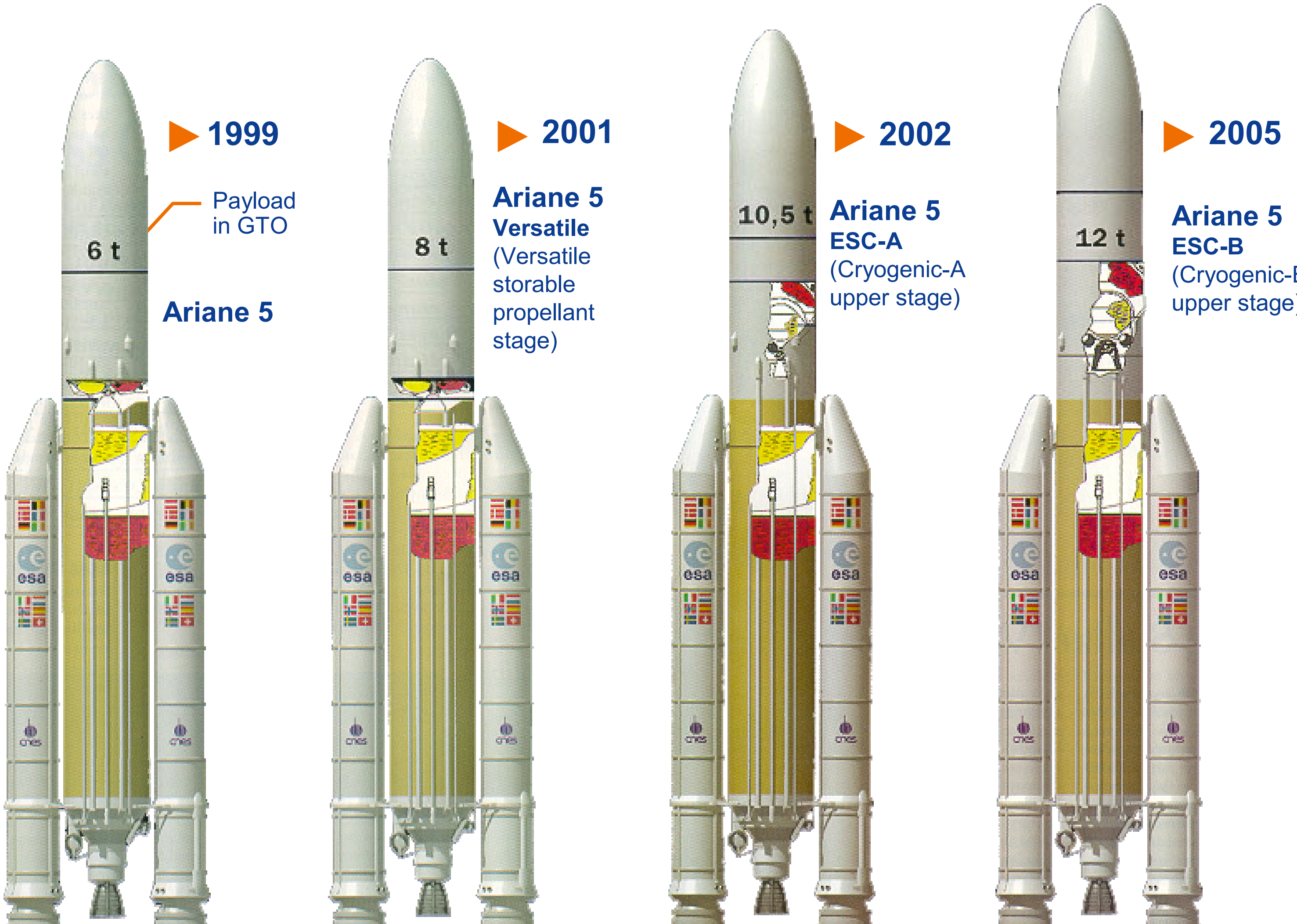
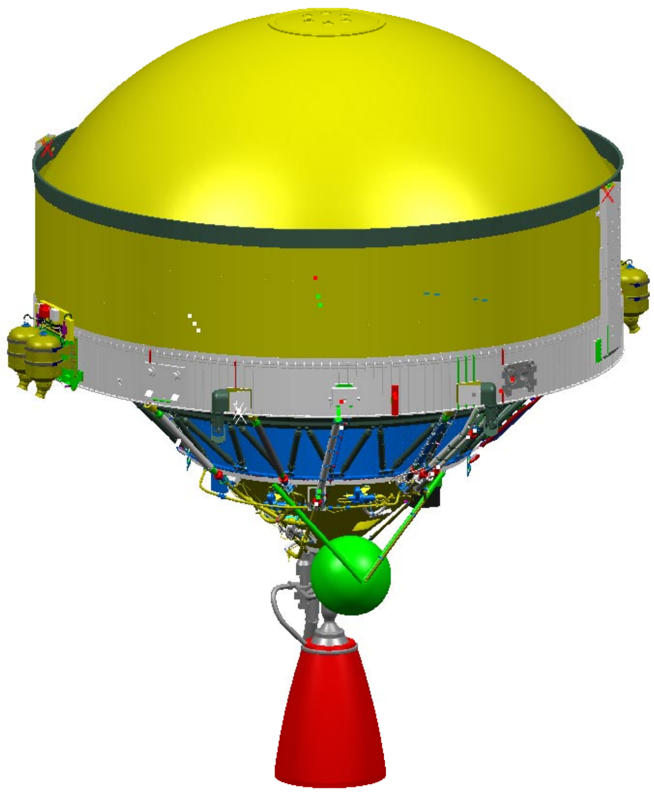
ESC-A is being developed by Astrium as prime contractor of CNES, the French space agency. CNES is managing the Ariane 5 development for ESA, the European space agency.

Placement of ESC-A in the Ariane 5 Development



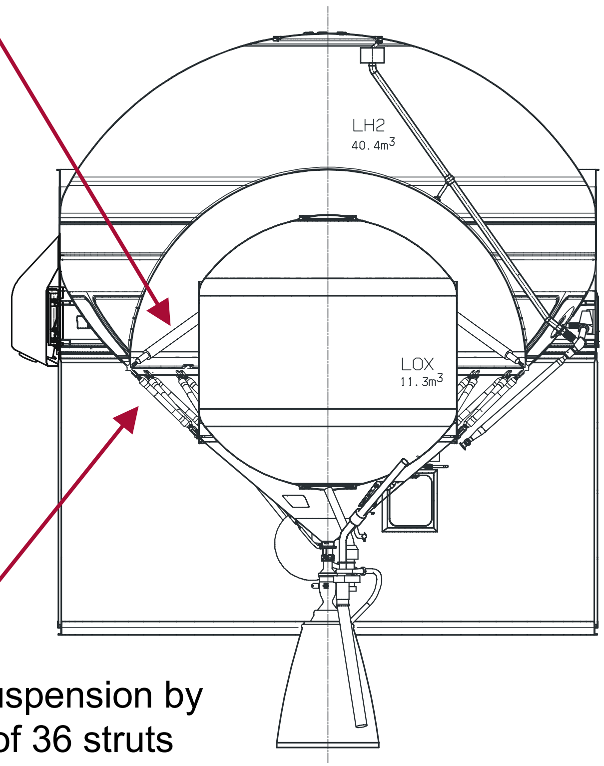
Lift-off mass	746 t	767 t	777 t	790 t

Design of the Upper Stage ESC-A



ESC-A Cryogenic Upper Stage

Position of SARO
friction damper struts



LOx tank suspension by
framework of 36 struts

Position of Friction Damper Struts and
LOx Tank Suspension in the ESC-A

Friction Damper System SARO

SARO = „Système Amortisseur Réservoir Oxygène"

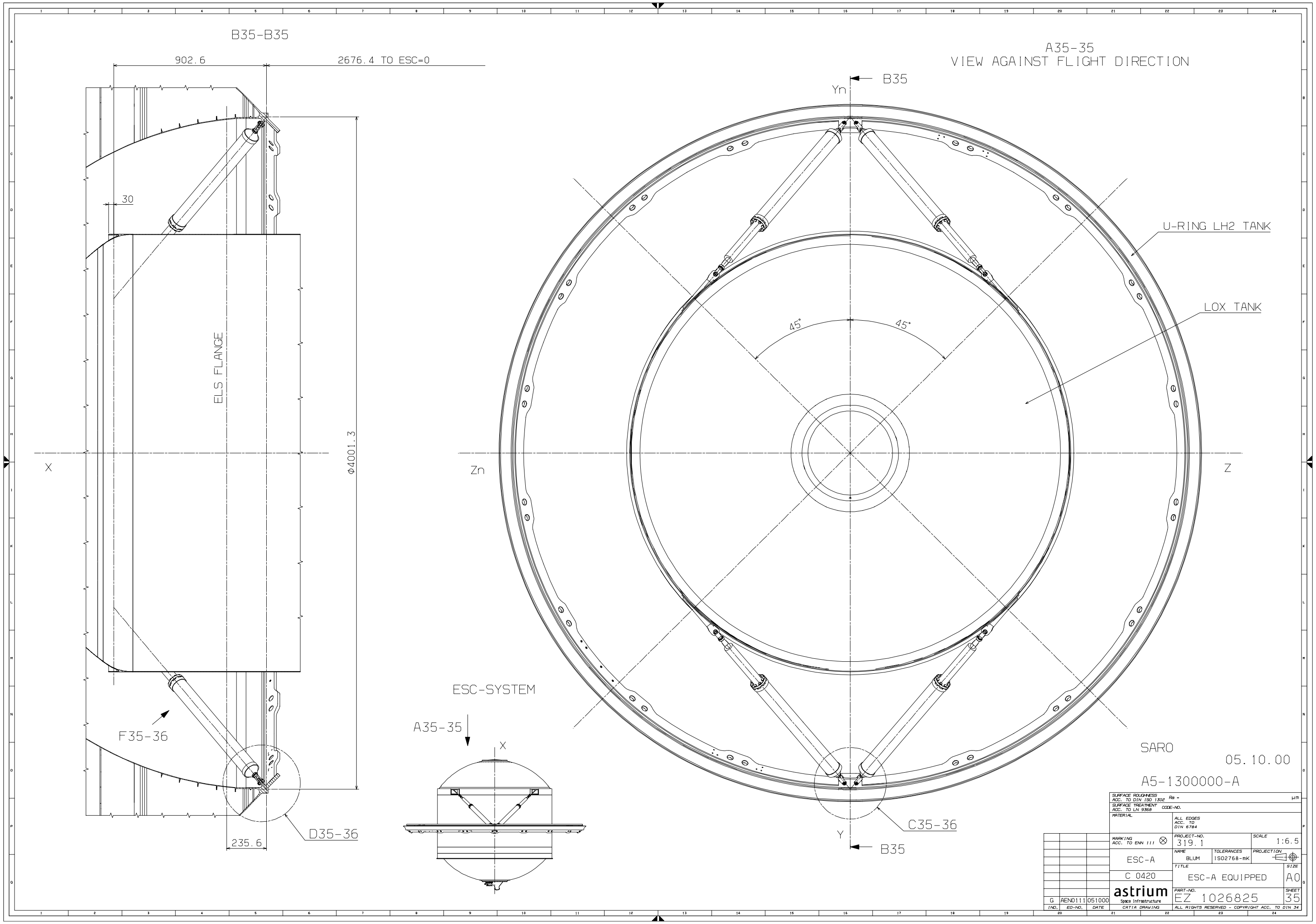
From Launcher System Analysis:

- 1st acoustic booster mode can lead to lateral bending modes of the launcher in case of asymmetric excitation.
- Coupling between lateral LOx tank and lateral payload oscillation exists.
- As a consequence, lateral payload response can significantly be reduced by introducing damping to the LOx tank.

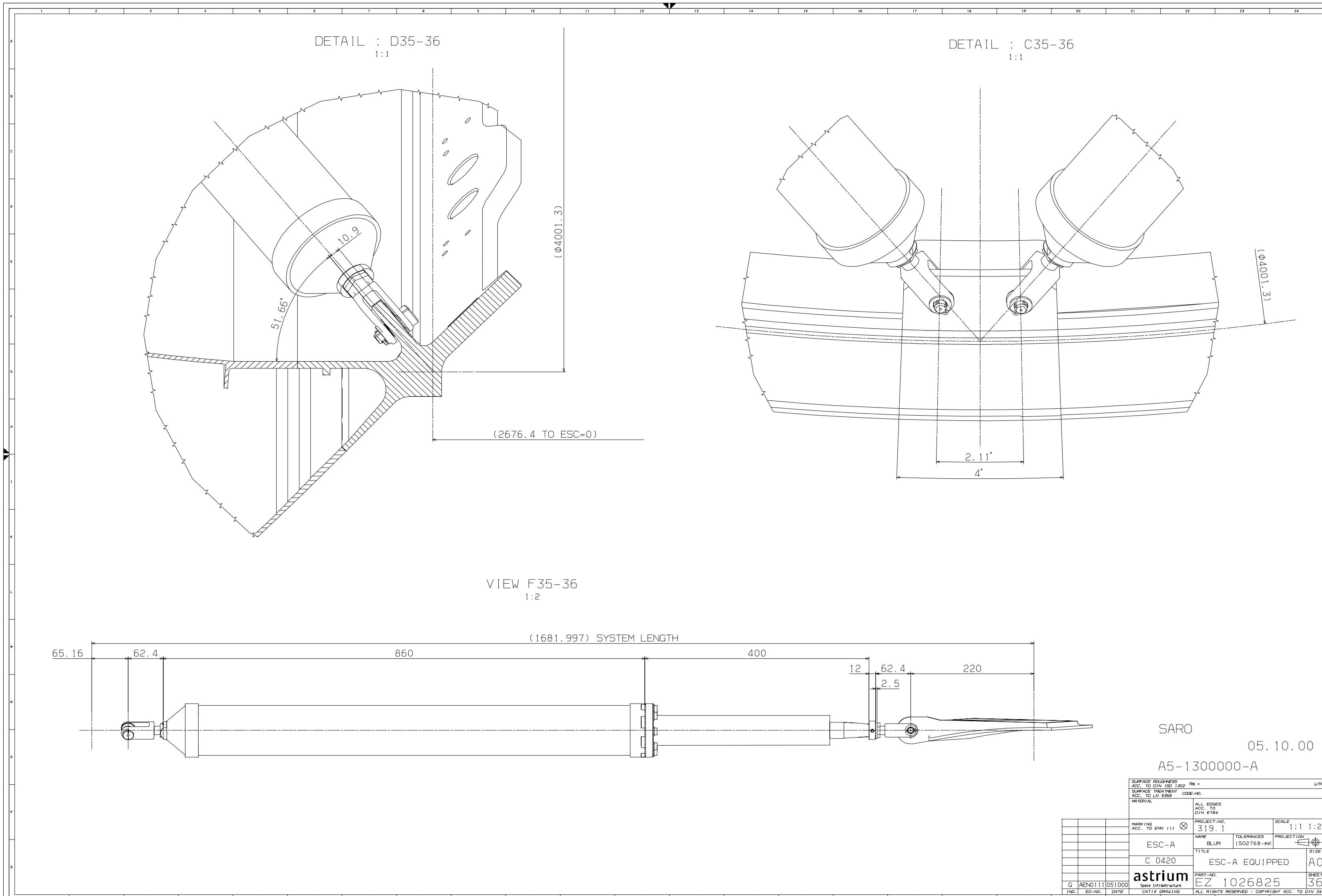
Technical Target of SARO:

to provide damping at amplitudes down to 0.1 mm over a distance of approx. 1.5 m at a frequency of 20 Hz under cryogenic temperatures

Position of Damper Struts



Design of Friction Damper System



/ Analysis Tasks

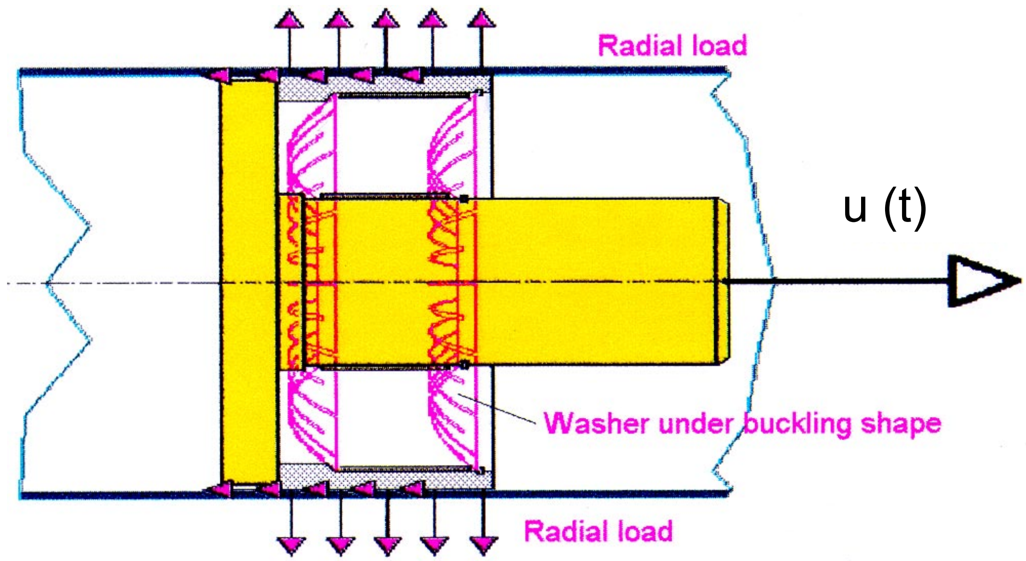
Contact analysis of ball bearings

Non-linear analysis of damper

Modal analysis of complete system

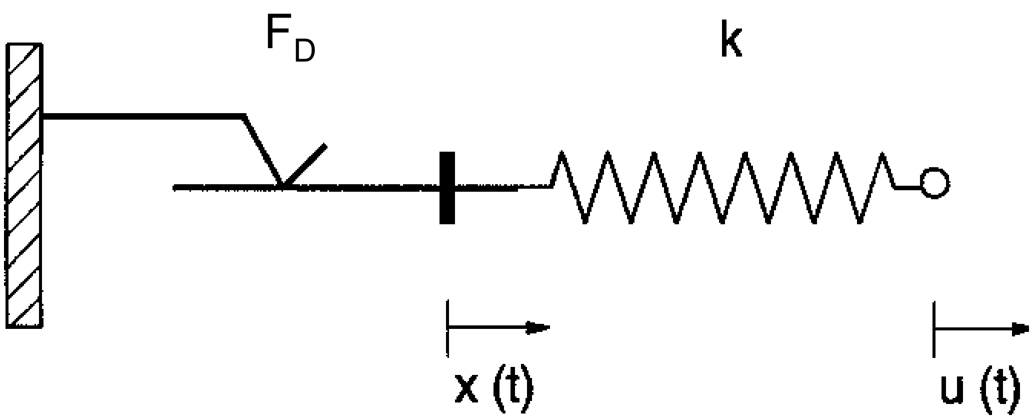
Non-Linear Analysis of Damper

Real damper design*):



*) picture by Jarret

Simplified analysis model:

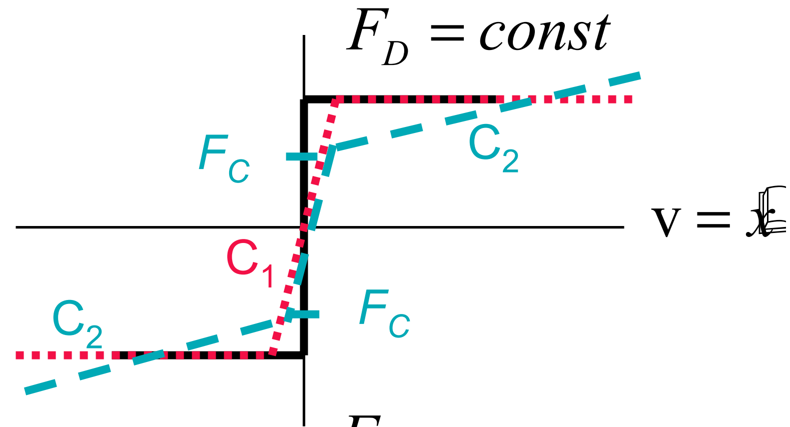


Non-Linear Analysis of Damper

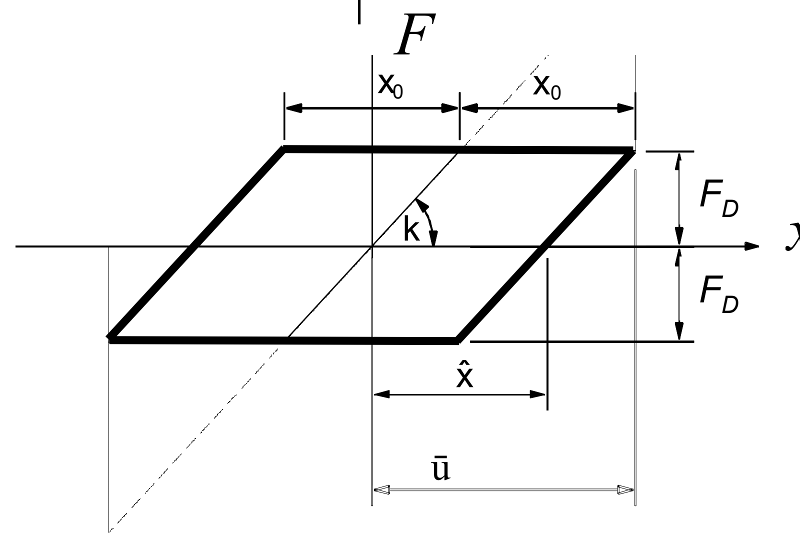
High non-linear force-velocity behavior of ideal Coulomb friction damper:

Force-velocity behavior used in Motion to prevent numerical instability of ideal damper

Force-velocity behavior used in Motion to approximate real friction damper



Phase diagram of elastically connected ideal Coulomb friction damper:



Dissipated energy per cycle for elastically connected ideal Coulomb friction damper:

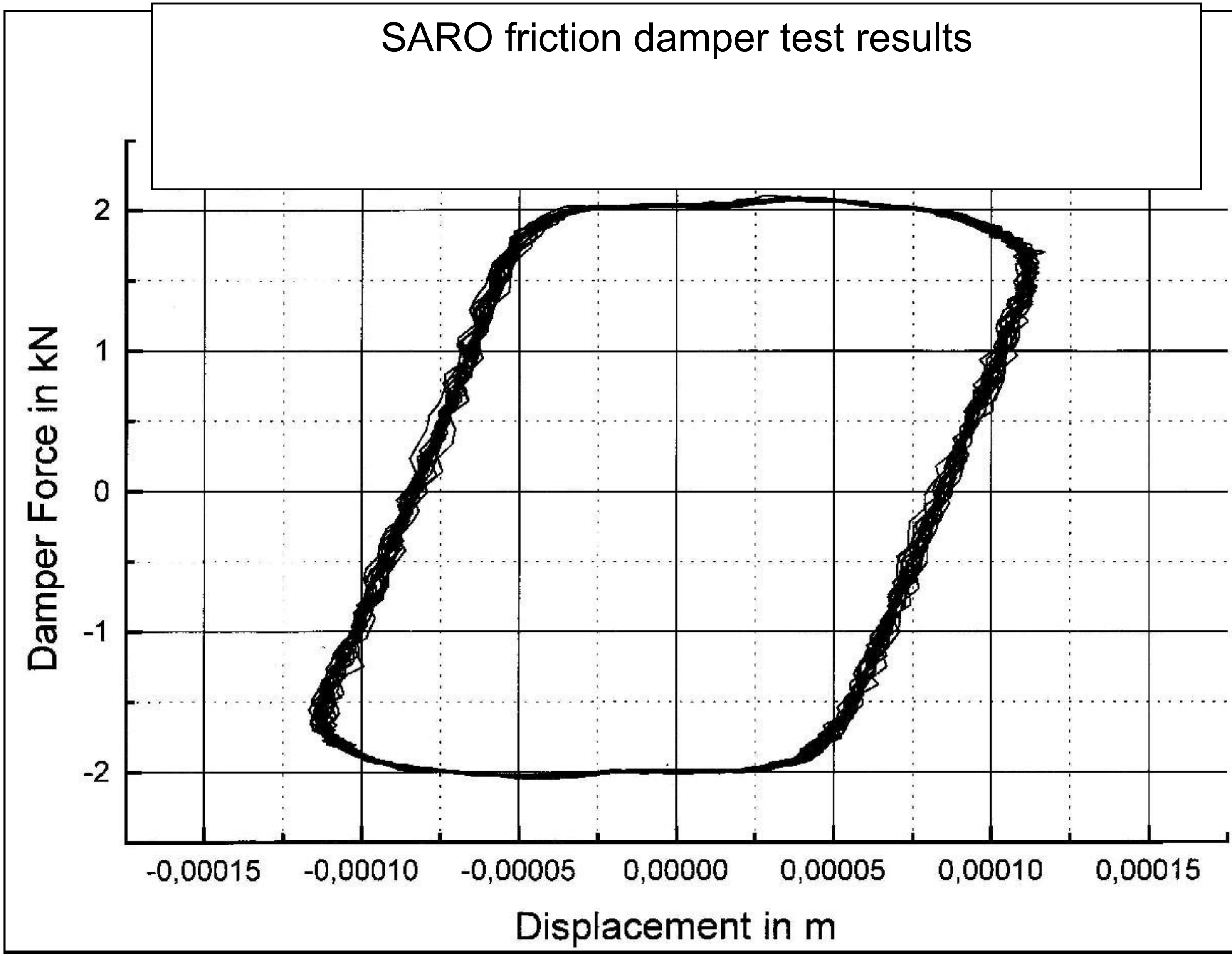
$$W_D = 4\,F_D \cdot \hat{u}\left(1 - \frac{F_D}{k \cdot \hat{u}}\right)$$

Non-Linear Analysis of Damper

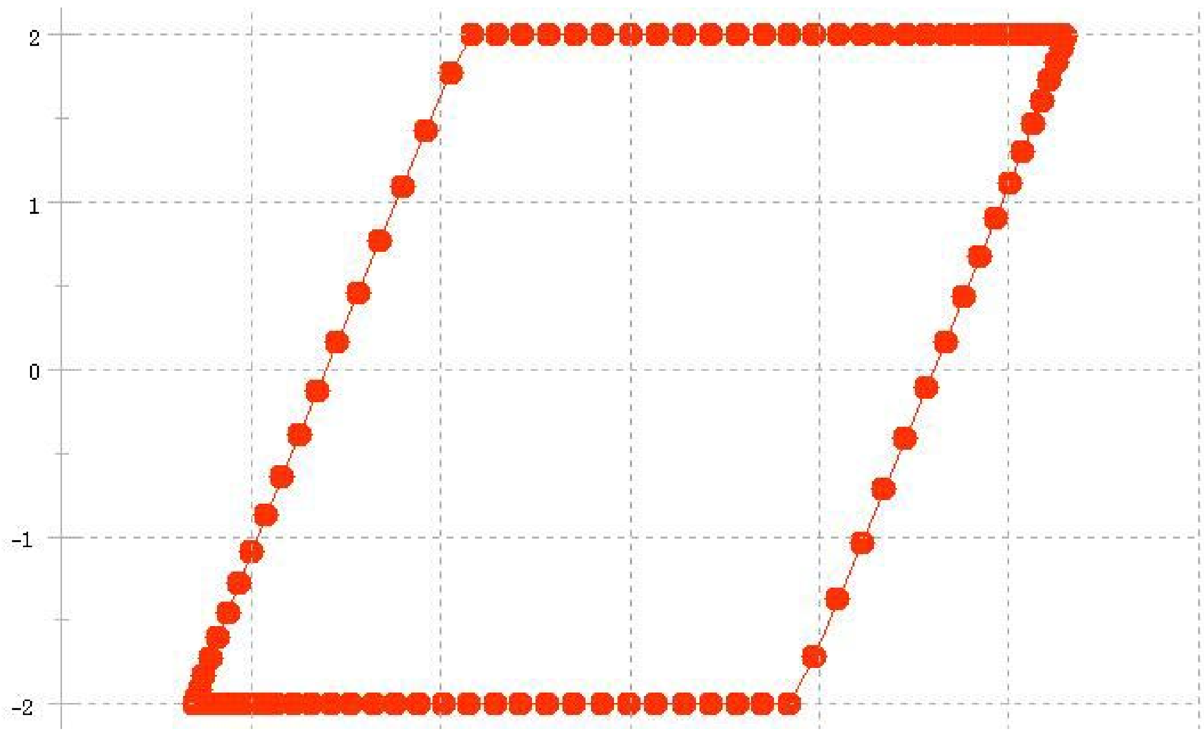
Tricks used in Pro/MECHANICA Motion to model friction damper:

- Damper force was modelled as computed measure with velocity-dependent force:
  - measure "ideal damper force" = bound(C_1v, -F_D, F_D)
  - measure "real damper force" = bound(C_1v, -F_C, F_C) + C_2v
  - damper joint axis load was then created of polynomial type as function of measure
- Linear spring used for spring in serial connection to damper
- Dissipated energy modelled as measure, evaluation method "integrated": measure = damper force x damper velocity
- Damper excitation modelled as position drive with cosine function

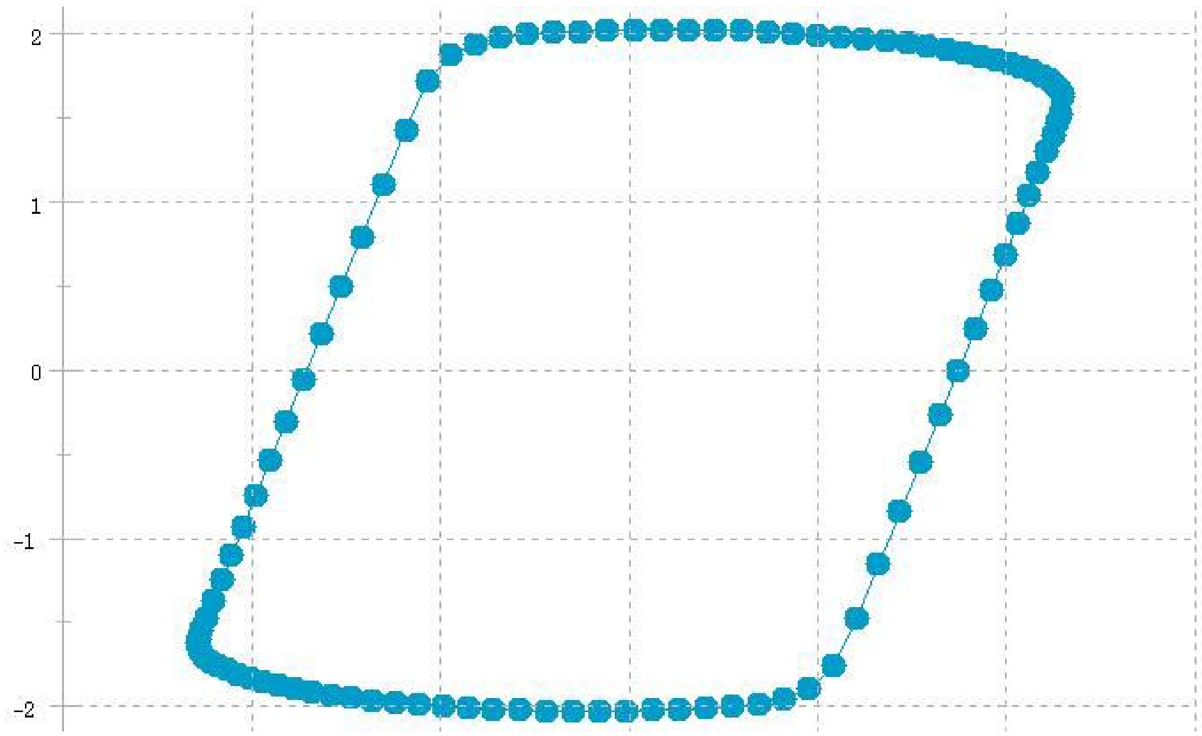
Non-Linear Analysis of Damper



Analysis results with ideal damper model



Analysis results with real damper model



Non-Linear Analysis of Damper

Comparison of Analysis and Test Results:

Max. Damper Friction Force:

Hand analysis with ideal damper:	2 kN
Pro/MECHANICA analysis with ideal damper:	2 kN
Pro/MECHANICA analysis with real damper:	2,03 kN
Test:	2,07 kN

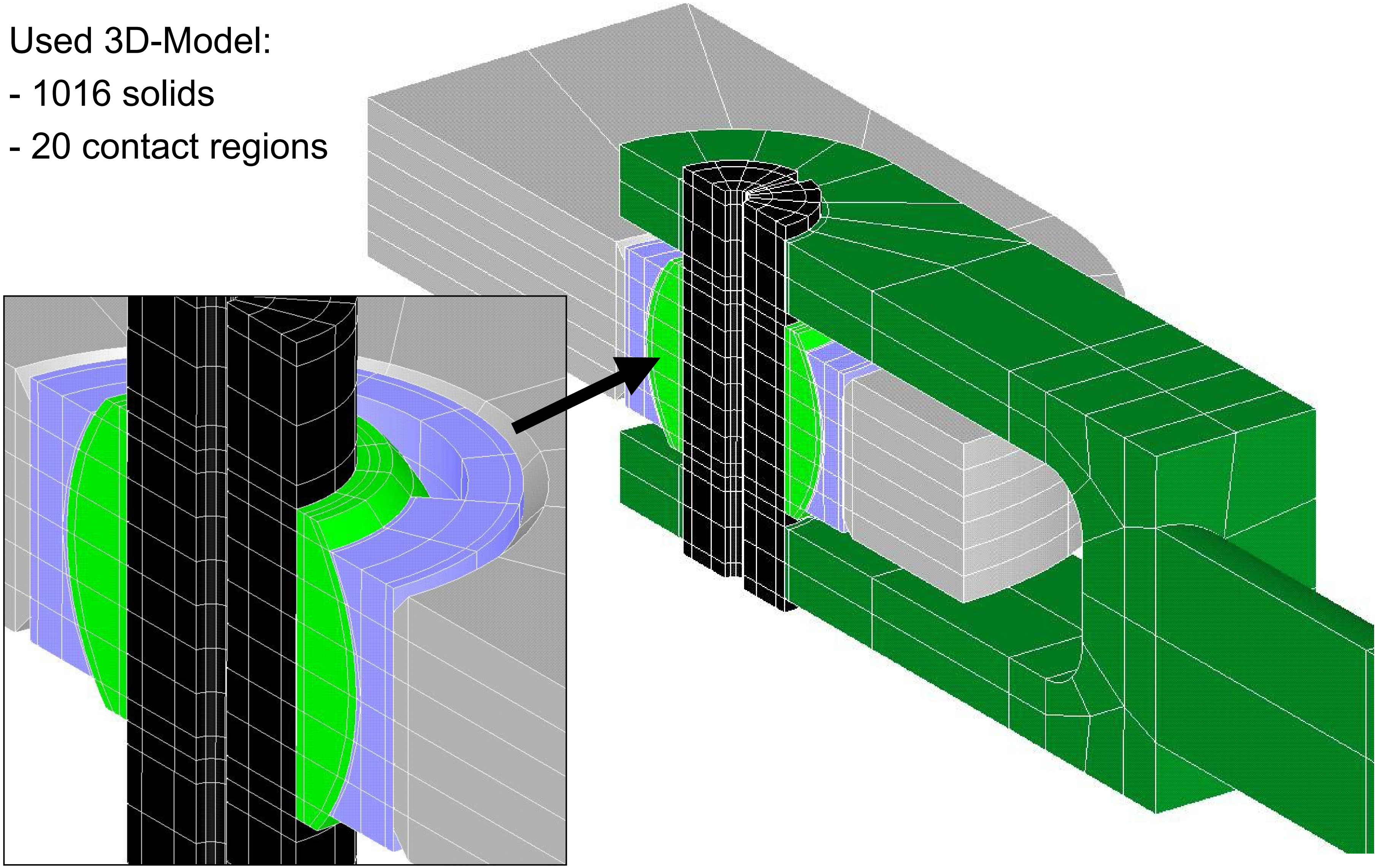
Dissipated Energy per Cycle:

Hand analysis with ideal damper:	0.63 Nm
Pro/MECHANICA analysis with ideal damper:	0.64 Nm
Pro/MECHANICA analysis with real damper:	0.67 Nm
Test:	0.68 Nm

Remark:
Error between ideal and real damper is bigger at other speeds!

Contact Analysis of Ball Bearings

Used 3D-Model:
- 1016 solids
- 20 contact regions



Contact Analysis of Ball Bearings

Methods used to model attachment elements in Pro/MECHANICA Structure:

- half model created (because of slot in bearing race, quarter model was not possible)
- all parts in contact (Aluminium lug, race, ball, bolt, hole in fork end) have been modelled with minimum and maximum interferences (= 2 models):
  - if all maximum interferences come together, this is called "tight fit case" = max. stiffness, but also max. friction moment
  - if all minimum interferences come together, his is called "loose fit case" = min. stiffness and min. friction moment
- mesh and contact regions created by hand
- single path adaptive analysis, one load increment
- stiffness of connection was analysed by comparing displacement of unloaded model (after contact analysis) with displacement of loaded model (tension load at fork end)
- friction moment was estimated by analysing the average contact pressure between ball and race

Contact Analysis of Ball Bearings

Goal is to reach sufficient stiffness of attachment elements by acceptable stresses in the parts and friction moments in the bearing!

Comparison of analysis results with test for:

- stiffness with 6500 N tension load
- rotational torque with assuming μ=0,04

	Interference [μm]:	Measured Stiffness [N/m]:	Analysed Stiffness [N/m]:	Measured torque [Nm]	Analysed torque [Nm]
Tight fit:	ball-race: 5 race-lug: 31 bolt-ball: 16 bolt-yoke: 17	1,71 E+8	1,75 E+8	14,9	15,6
Loose fit:	ball-race: 3 race-lug: 6 bolt-ball: 8 bolt-yoke: 8	1,47 E+8	1,55 E+8	9,0	6,3

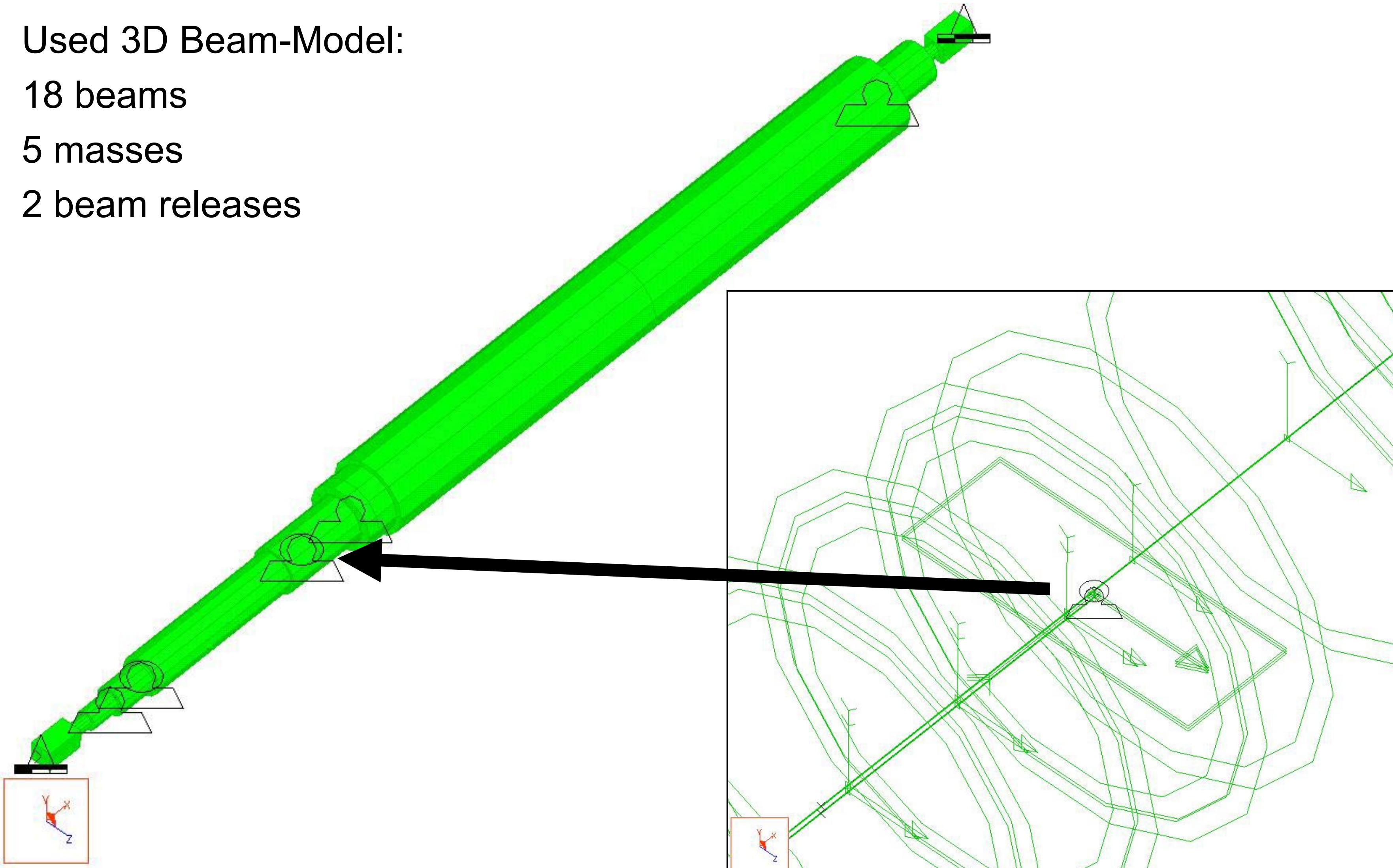
Modal Analysis of Complete System

Used 3D Beam-Model:

18 beams

5 masses

2 beam releases



Modal Analysis of Complete System

Methods used to model SARO struts in Pro/MECHANICA Vibration:

- full model created with beam elements and representative cross sections/stiffnesses
- damper modelled with two beam structures (inner and outer tube) and cross beams to model guiding bearings in damper; beam release used to model moment-free bearing connection
- point masses used to model mass concentrations of flanges or other parts

Comparison of first fundamental bending frequency:

- test result: 78,9 Hz
- analysis result: 80,6 Hz

Conclusion

All modules of Pro/MECHANICA gave results, which were in good agreement to the measurements:

Non-Linear Analysis of Damper in Motion:

- Error in energy dissipation 2-6 %

Contact Analysis of Ball Bearings in Structure:

- Error in stiffness estimation: 2-5 %
- Error in friction torque estimation: 5-30 %
  (but nature scatters similar for “equivalent” bearings!)

Modal Analysis of Complete System in Vibration:

- Error in frequency estimation: 2 %