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Innovative Produkt Simulation

Simulation of a clamping ring under high dynamic loading

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Overview

14th May 2009

- Introduction
  - Use of clamping rings / Dynamic issue
- CAE Process
- Validation (1st Task)
  - Correlation of testing and simulation / Quasi-static pull-out test
  - Numerical effects using LS-DYNA Explicit for a pull-out test
- Design Parameter (2nd Task)
  - Influence of different design parameters of the clamping ring
- High Dynamic Load (3rd Task)
  - Impeller burst of a turbo engine / Different failure scenarios
- Summary

Introduction

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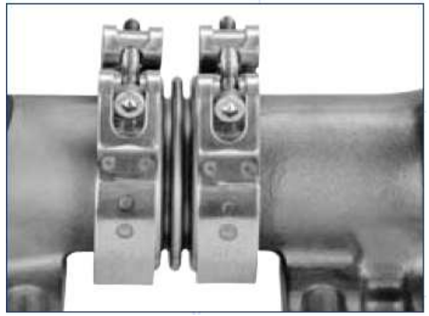
- Use of clamping rings
  - Connection of two or more parts at the cylindrical flanges


- Examples of common application
  - Several kinds of tubes and pipes or pressure vessels and tanks



- Application in turbo engines
  - Connection of the compressor, turbine and bearing casing of smaller turbo chargers and turbo pumps

Introduction

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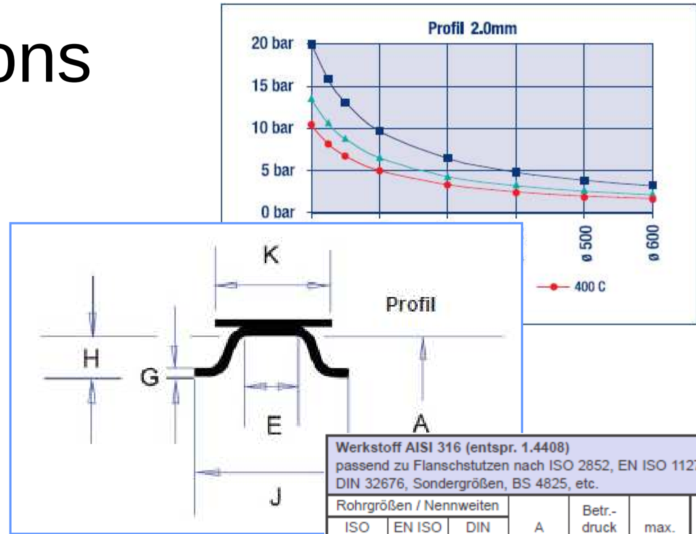
- Design for normal operating conditions
  - Standard rules and supplier guide lines
  - Simple static analyses



Werkstoff AISI 316 (entspr. 1.4408) passend zu Flanschstutzen nach ISO 2852, EN ISO 1127, DIN 32676, Sondergrößen, BS 4825, etc.						
Rohrgrößen / Nennweiten			A in mm	Betr.-druck in bar bei 150° C	max. Test-druck	Gewicht in g
ISO 2852 (Zoll)	EN ISO 1127 (NW)	DIN 32676 (DN)				
6⅝"	150	150	187,0	10	50	1690
8"			220,0	10	50	2190
8⅝"	200	200	238,0	10	50	2340
10"		250	272,0	5	30	2780
10"s.5	250		289,5	4	20	2970
12"		300	322,0	2	10	3370
12"s.5	300		340,0	2	10	3690

- Design for highly dynamic loading due to misuse or failure
  - E.g. shock waves, compressor surge, impeller burst
  - Consideration of the effects of the highly dynamic loading (impulse transmitted, mass inertia, non-linear material behaviour, complex contact situation)
  - This can be done using an explicit code like LS-DYNA

Introduction

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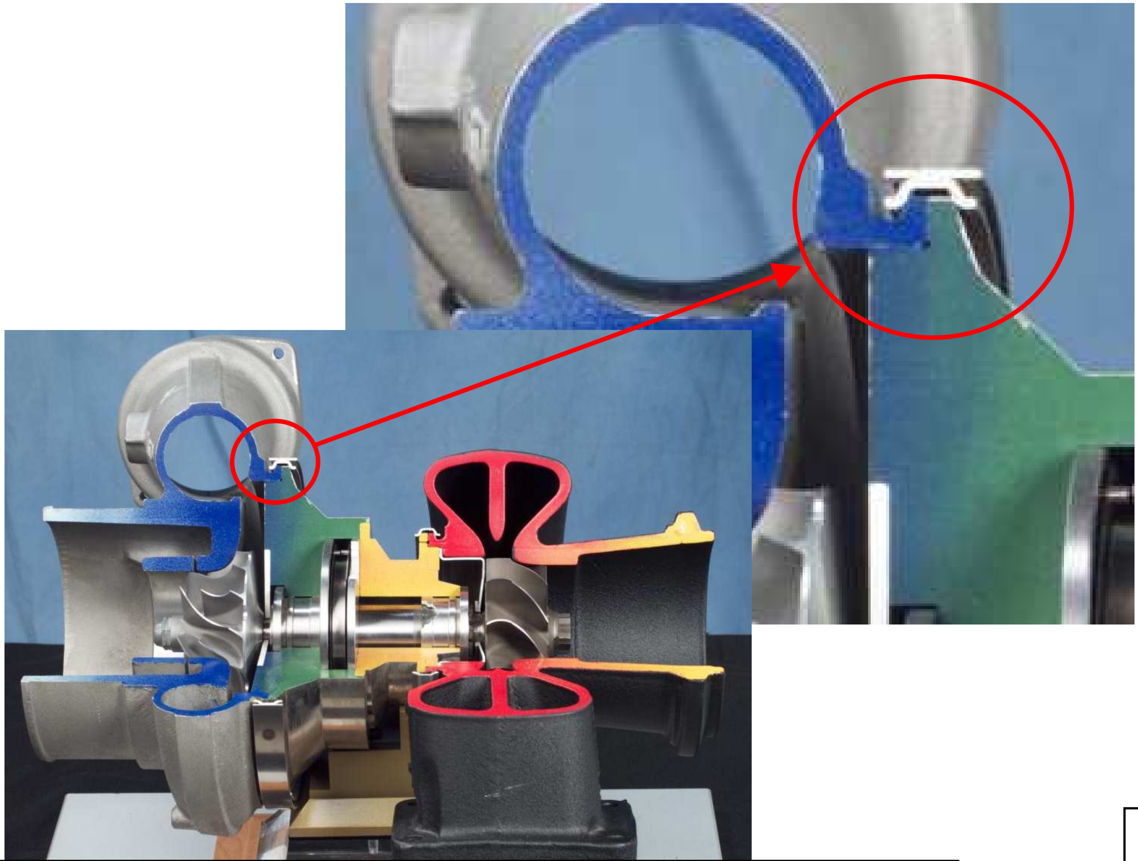
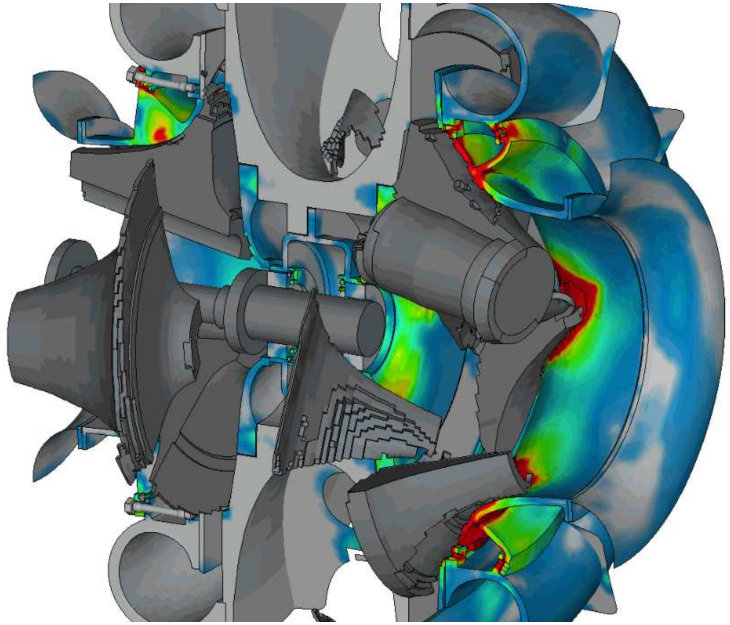
- Examples: Use of clamping rings in turbo engines



Use of the clamping ring in order to connect the compressor and bearing casing

see avi-movie 01



Demonstration model of a typical containment simulation of a turbo charger with highly dynamic loading

CAE Process

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- Aim
  - Designing a clamping ring for the worst-case scenario of an impeller burst of a small turbo charger
  - The connection of the compressor and bearing casing by the ring must be ensured even for such a highly dynamic loading

- CAE process
  - 3 steps lead to a reliable design
  - 1st task: a quasi-static pull-out test to validate the CAE technique
  - 2nd task: a parameter analysis of the clamping ring (optionally for better knowledge of essential design parameters)
  - 3rd task: the burst simulation meaning the highly dynamic loading

Pull-Out Test

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- Introduction
  - The 1st task in the CAE process is a simulation of a quasi-static pull-out test in order to validate the CAE technique
  - A quasi-static pull-out test with real hardware turbo charger parts was carried out as a basis for this validation
  - The focus of the validation is on the matching of the load-versus-deflection-curve and the maximum static load capacity
- CAE technique
  - Comparison of the test rig in trial and in simulation
  - Modelling of the pre-stressing of the clamping ring
  - Quasi-static pull-out test in simulation (LS-DYNA Explicit)

Pull-Out Test

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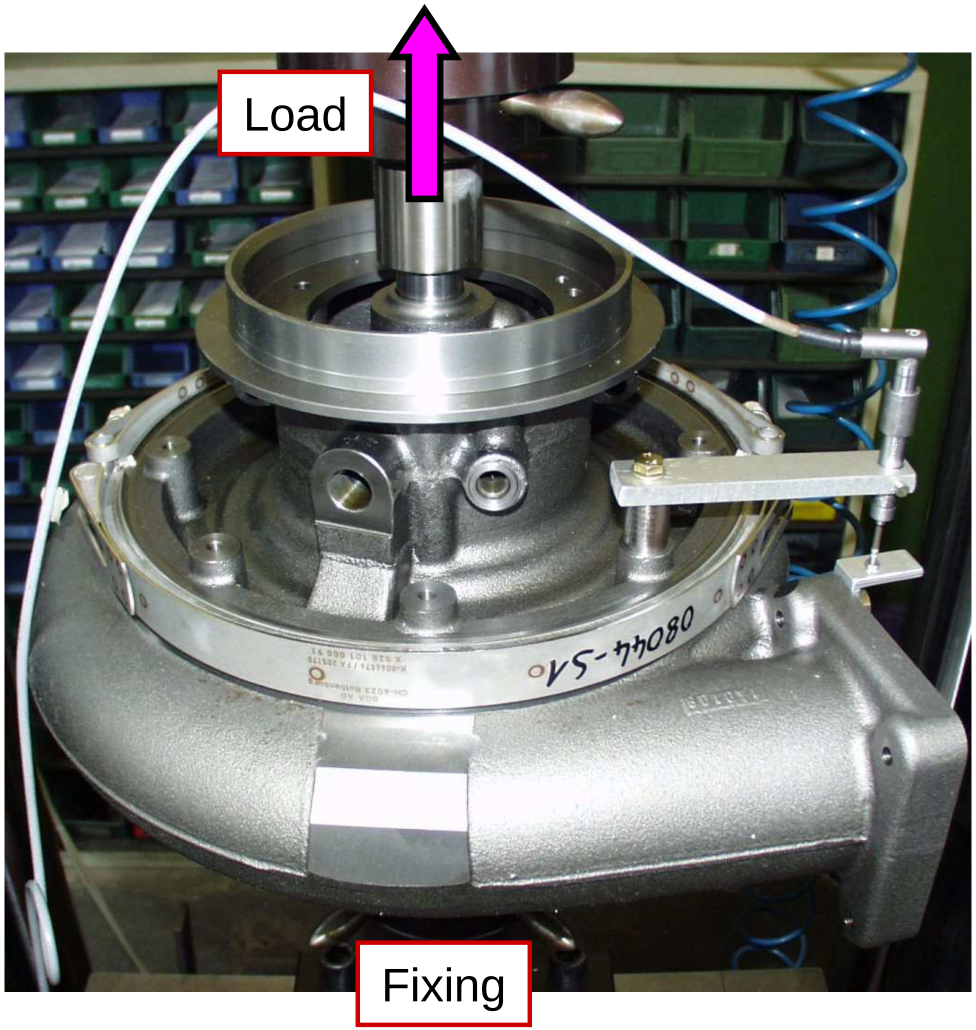
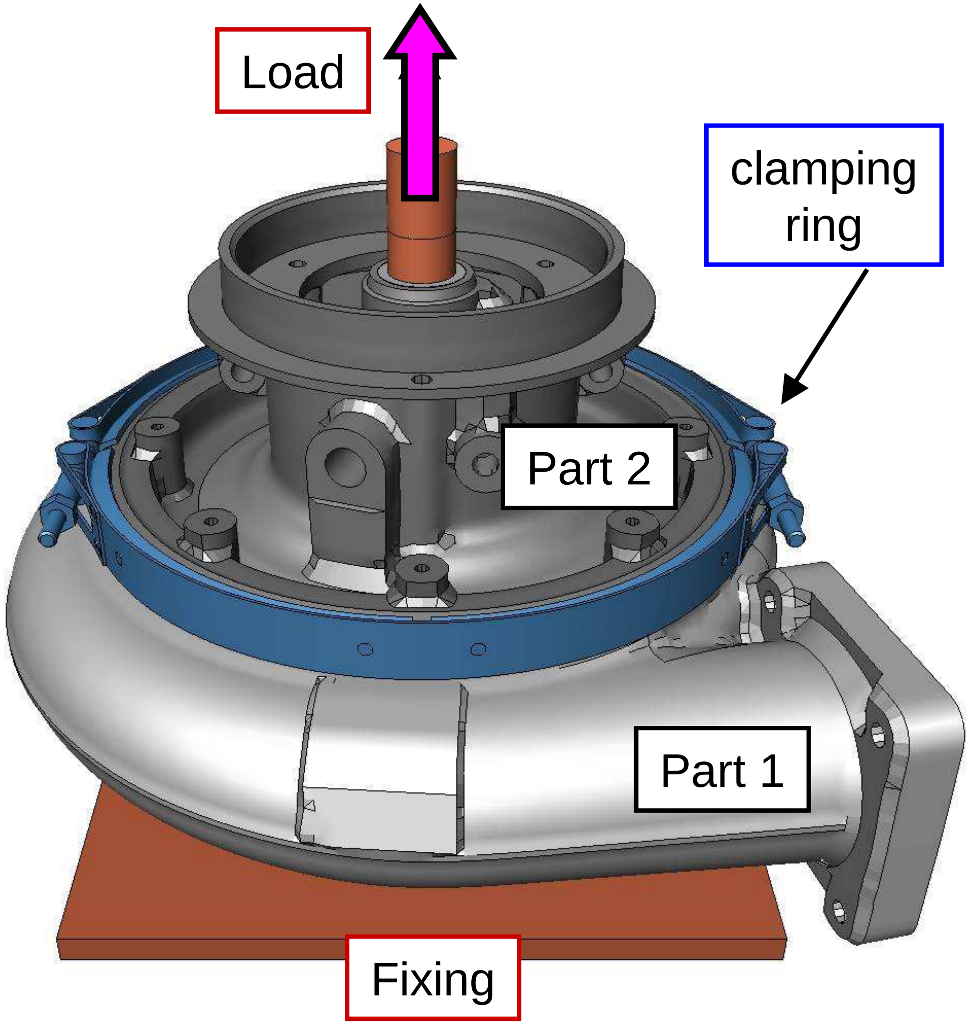
- Test ring in trial and in simulation





Pull-Out Test

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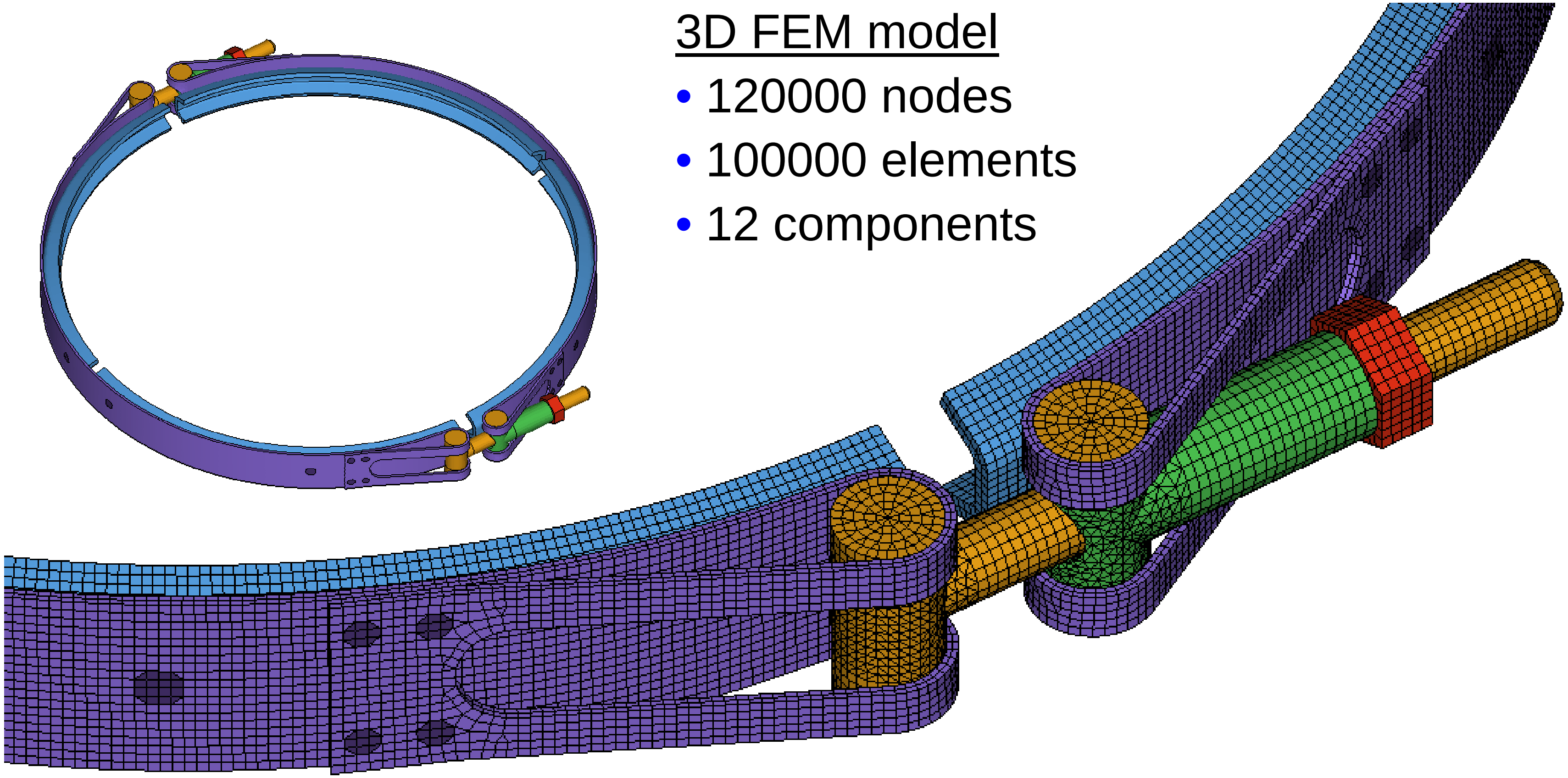
- CAE model technique
  - Typical CAE model of a clamping ring for crash simulation



3D FEM model
- 120000 nodes
- 100000 elements
- 12 components

Pull-Out Test

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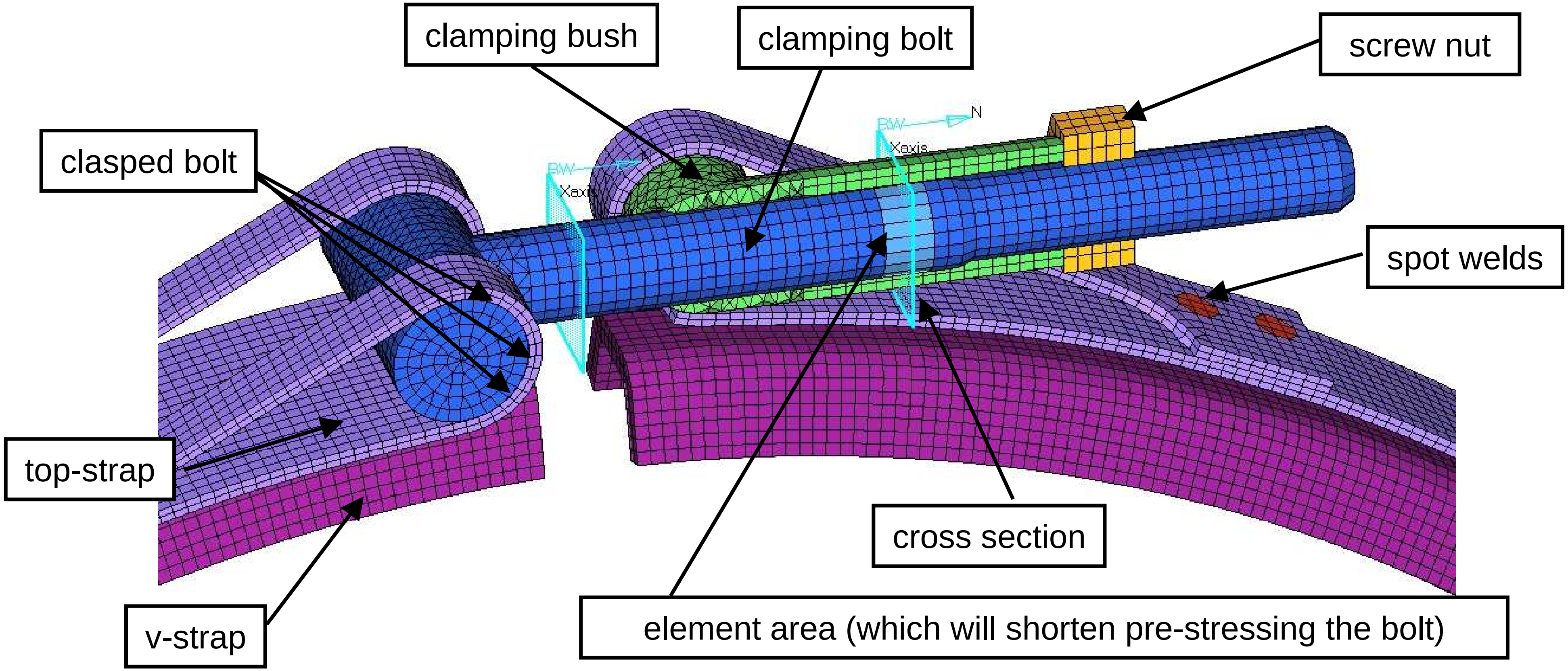
- CAE technique of the pre-stressed clamping ring
    - 3D model of the clamping ring using brick and tetra elements only



Pull-Out Test

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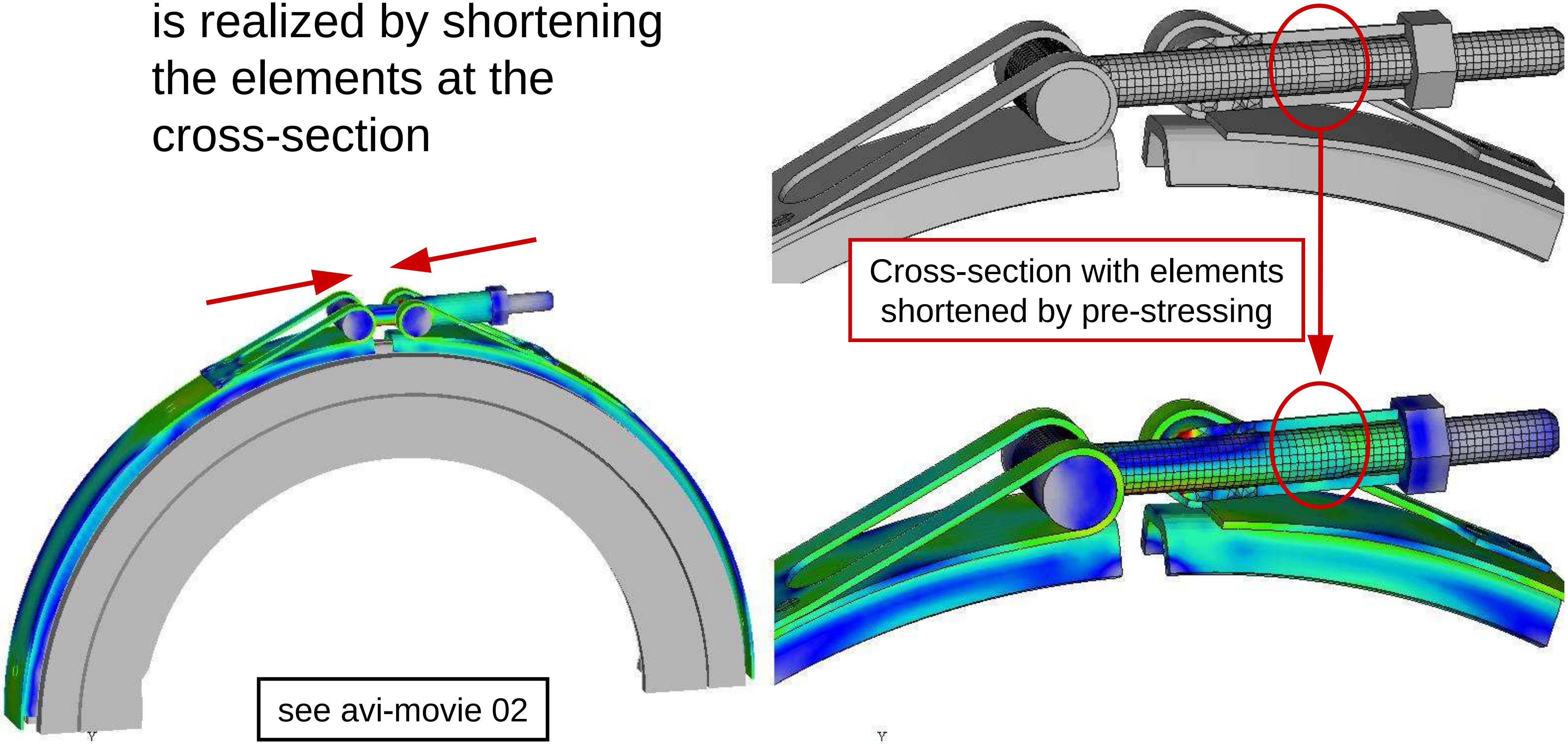
- CAE technique for pre-stressing the clamping ring
  - Pre-stressing of the bolts is realized by shortening the elements at the cross-section



Pull-Out Test

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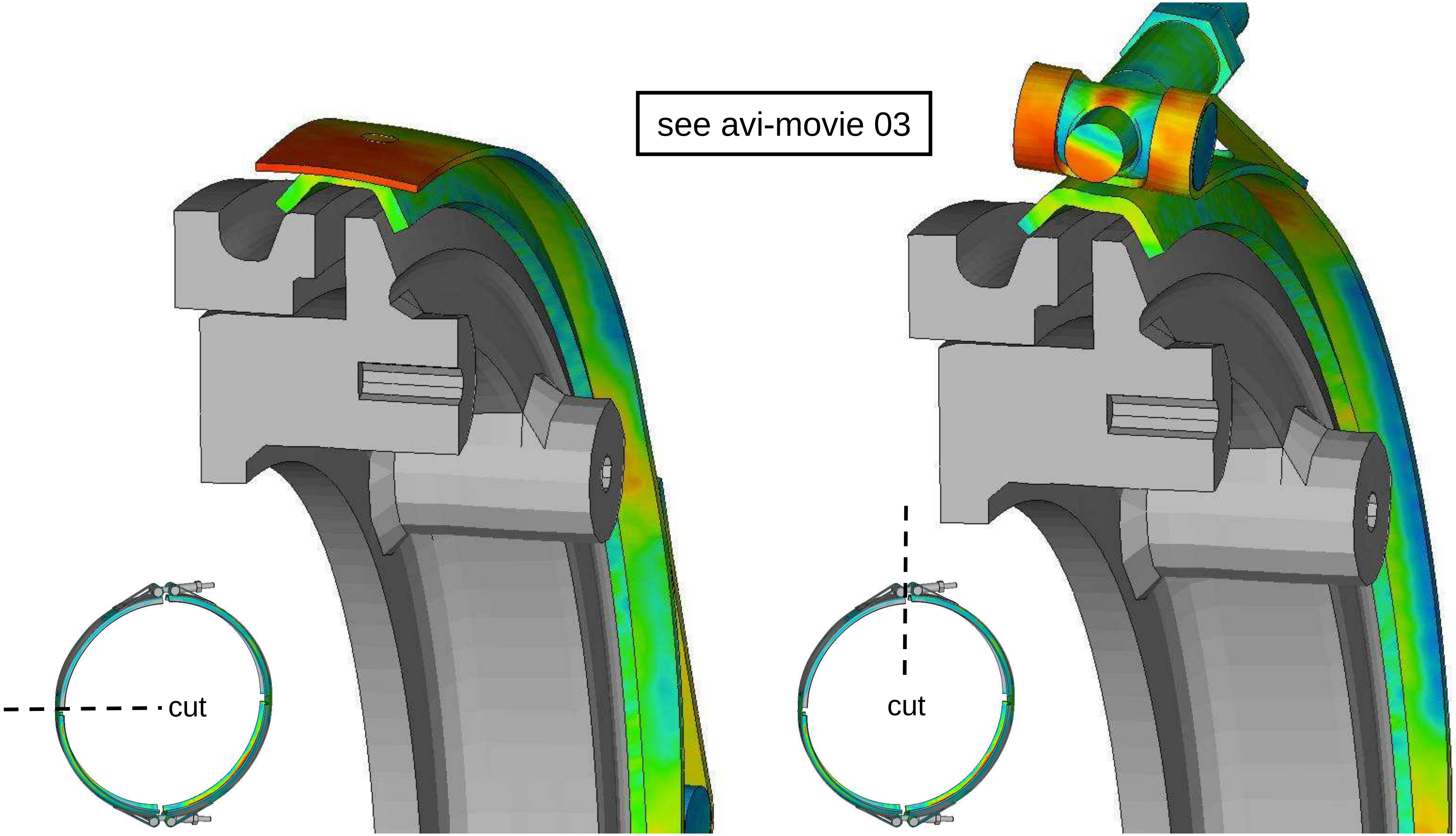
- Quasi-static pull-out test in simulation

see avi-movie 03



Pull-Out Test

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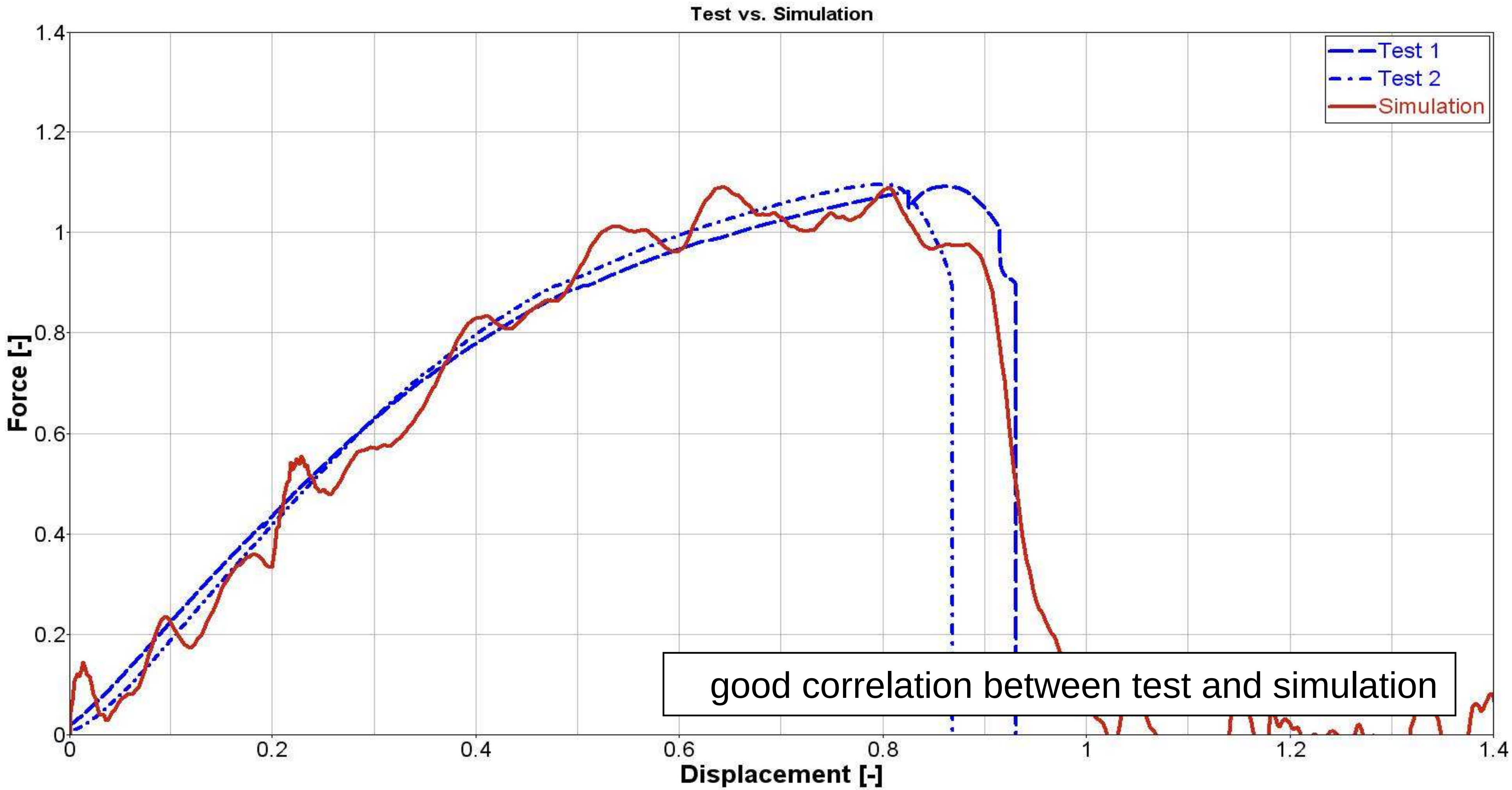
- Quasi-static pull-out test in simulation and trial



Pull-Out Test

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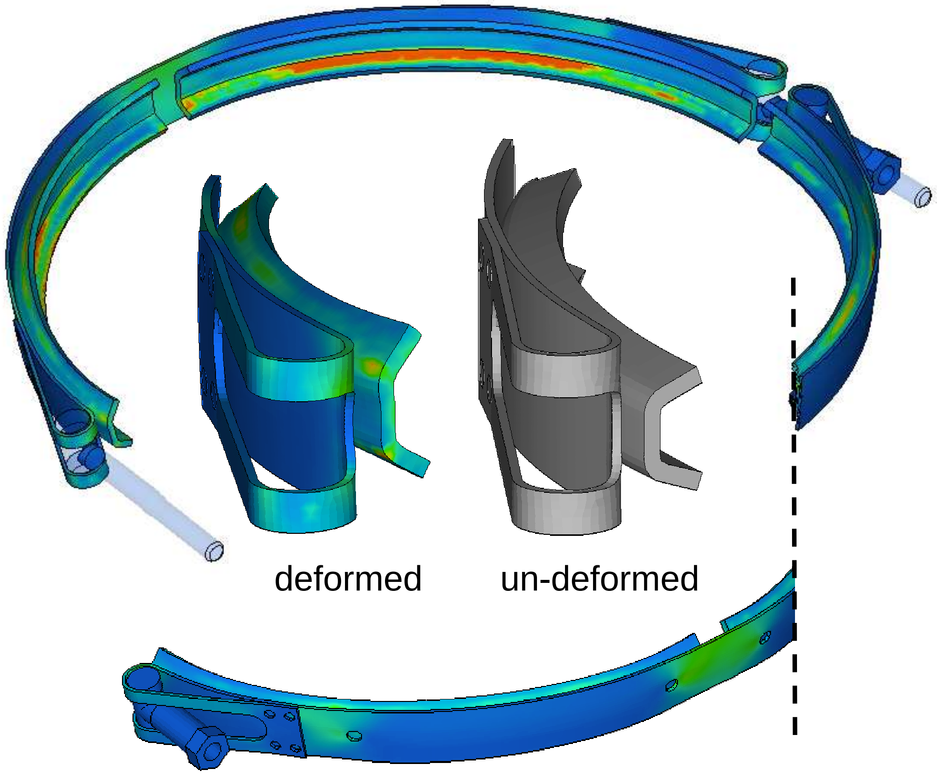
- Quasi-static pull-out test in simulation and trial
  - Good correlation between test and simulation



significant plastic deformation of v-shaped lower strap

split line for presentation

Pull-Out Test

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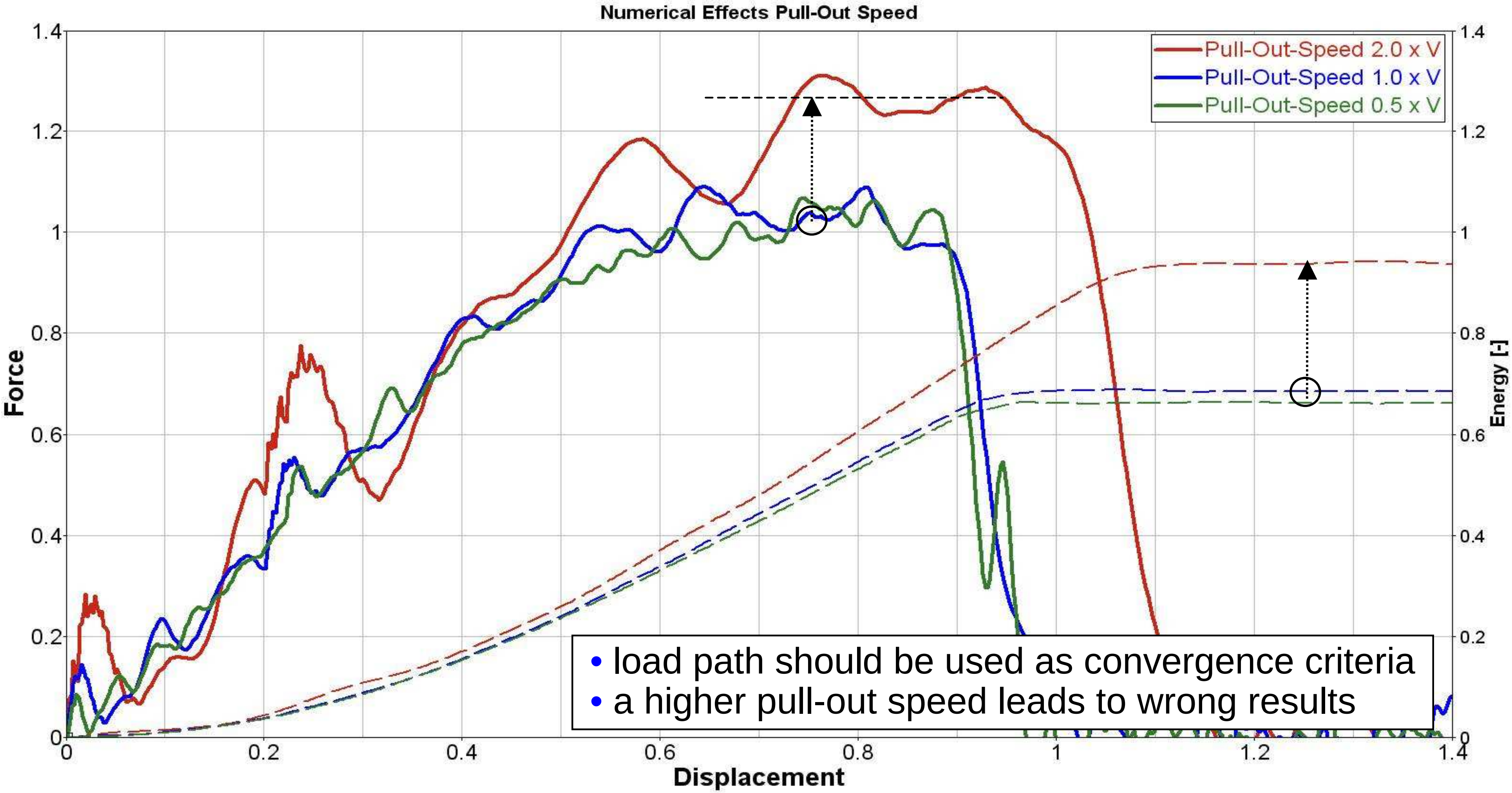
- Use of LS-DYNA Explicit for quasi-static analysis



Parameters

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- Introduction
  - The 2nd CAE task is a parameter analysis of the clamping ring for getting a better knowledge of the essential design parameters
  - This task is optionally, and shown here in order to demonstrate how design issues can be analysed very clearly by simulation
- Typical design parameters
  - The number of the segments of the v-shaped lower strap
  - The thickness of the lower v-strap or of the top strap
  - The number of the bolts
  - The material properties / data
  - etc …

Parameters

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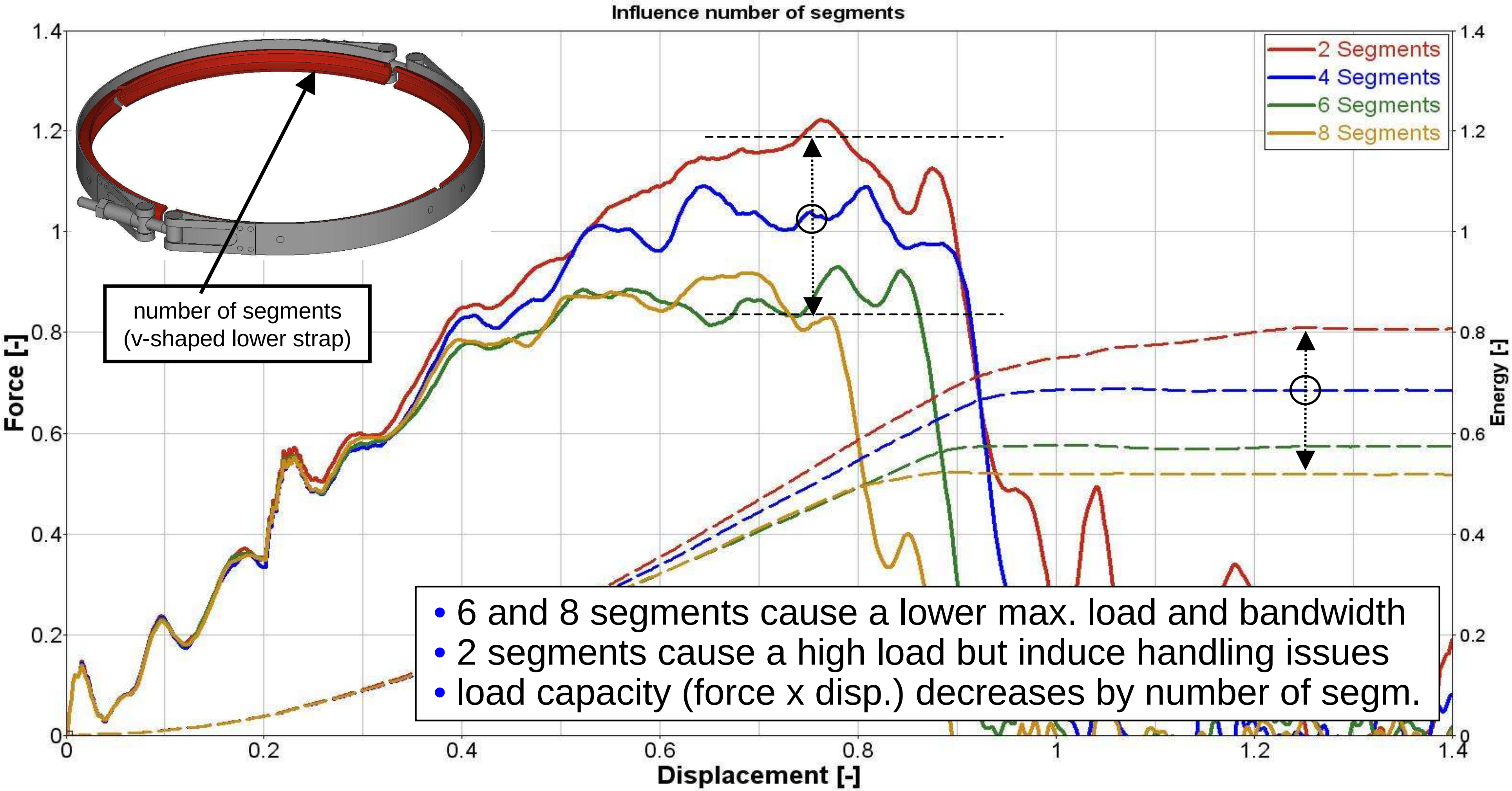
- Influence of the number of the segments of the lower strap



Parameters

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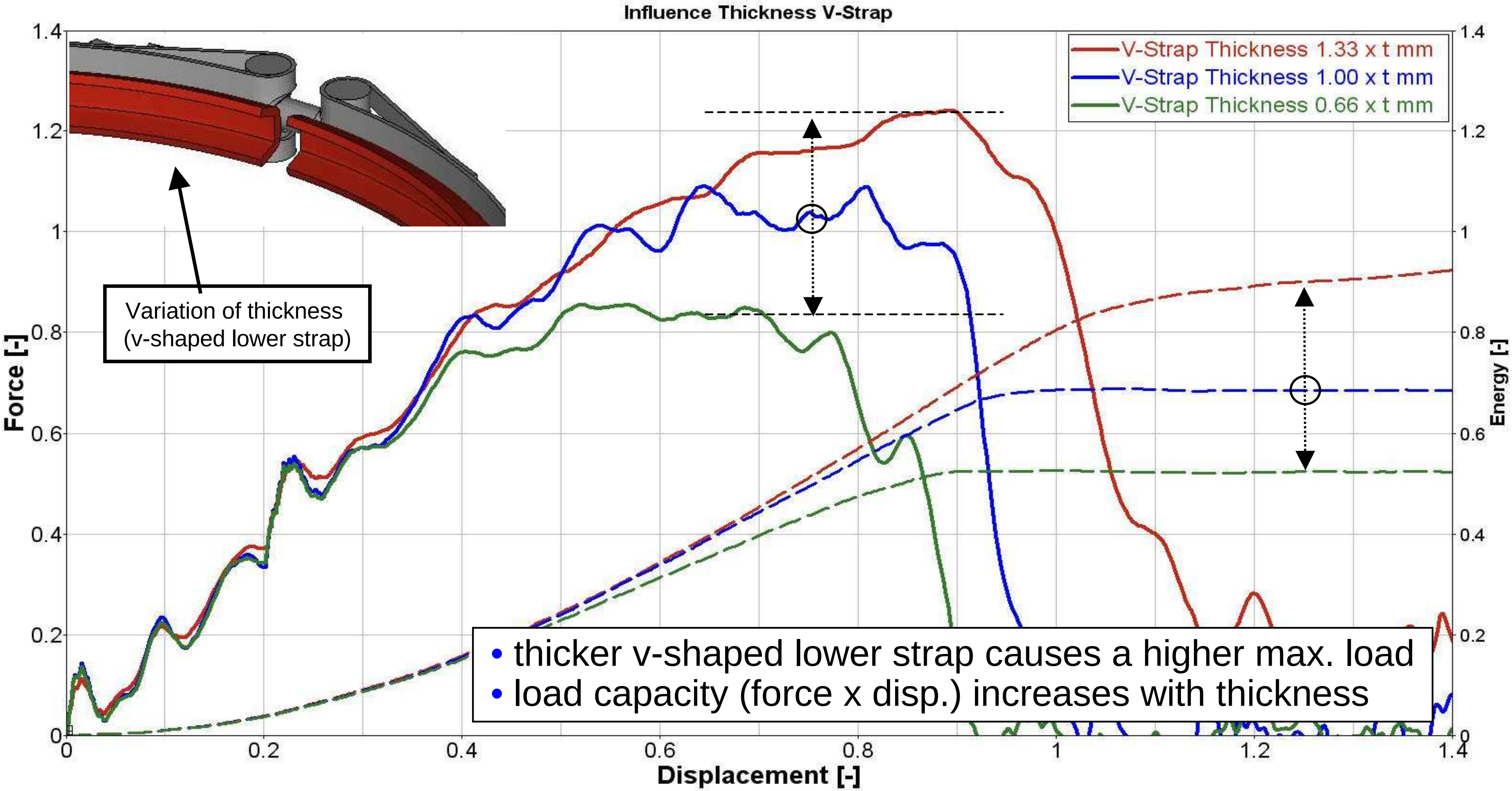
- Influence of the thickness of the v-shaped lower strap



Parameters

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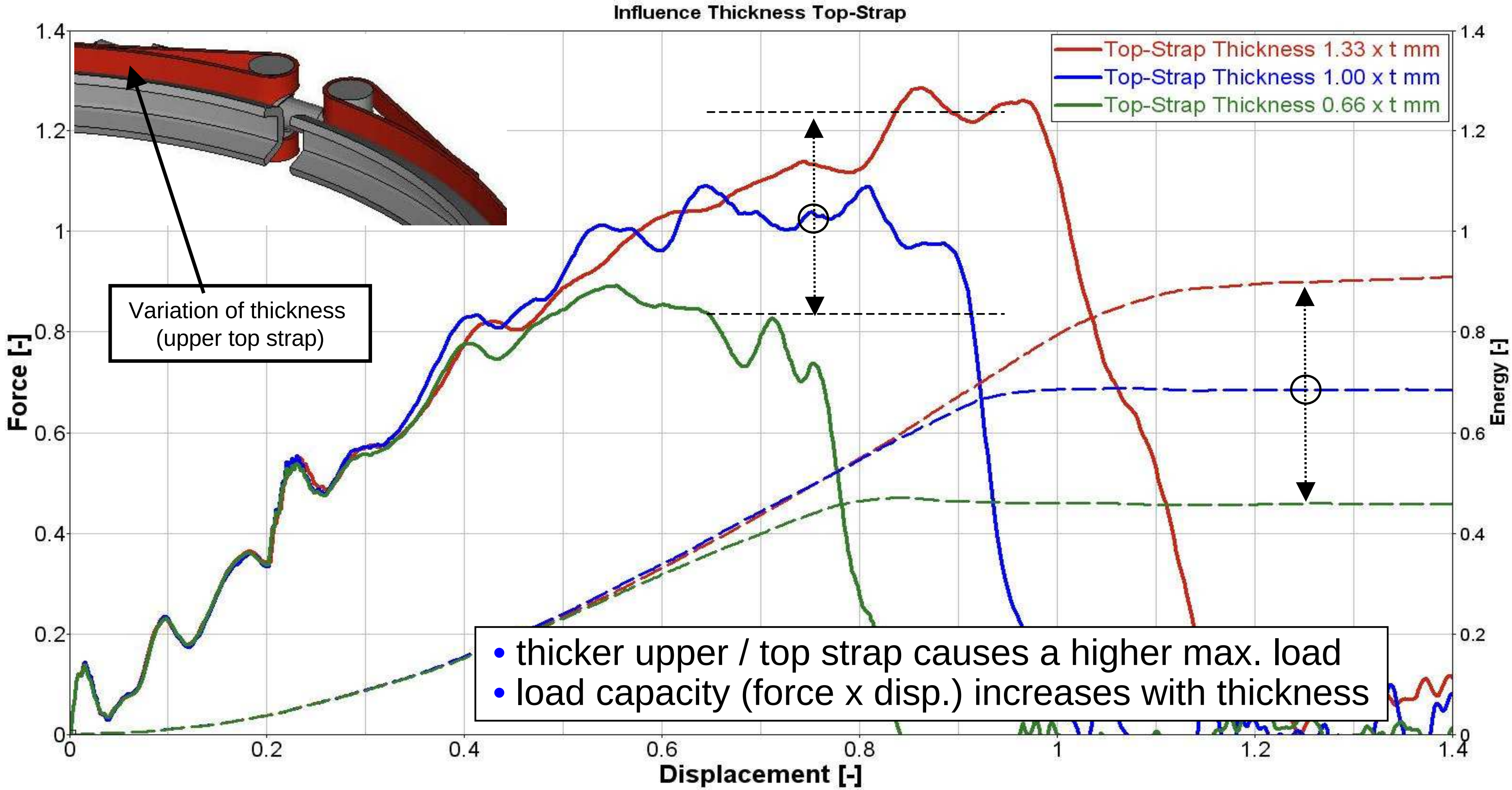
- Influence of the <u>thickness</u> of the upper <u>top strap</u>



- thicker upper / top strap causes a higher max. load
- load capacity (force x disp.) increases with thickness

Dynamic load

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- Introduction
  - The 3rd CAE task is the burst simulation of an impeller burst of a turbo charger with its highly dynamic loading of the clamping ring
  - Non-linear material behaviour, dynamic strain rate effects, high rate of plastification with failure, high geometric deformation and the complex contact situation have to be taken into account
  - Due to the validation done with the quasi-static pull-out test, the CAE model is reliable for crash simulation purposes too

- CAE technique
  - Using the presented CAE model for explicit analyses
  - Comparison of the forces in dynamic vs. static load case
  - Stiffness balance of the clamping ring and the structure

Dynamic load

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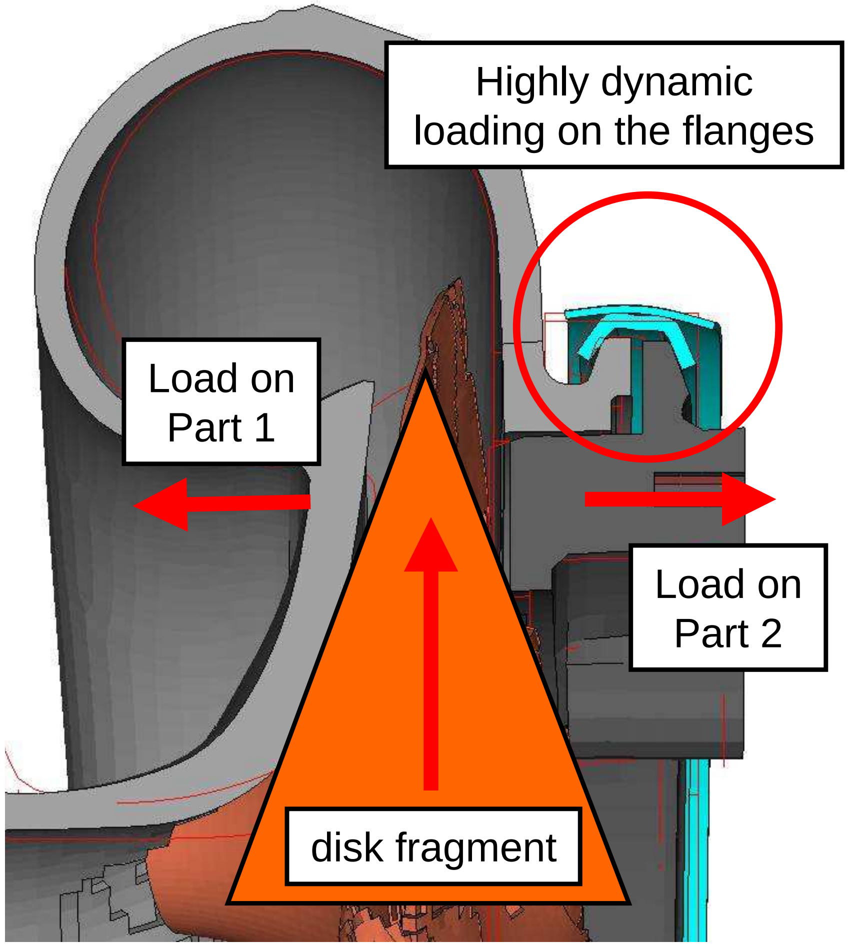
- Containment load case due to the impeller burst
  - Failure of the impeller (compressor wheel) releases a high amount of energy and impact load
  - The disk fragments move radially entering the airflow channel towards the casing spiral
  - Acting like wedges, they introduce a high bending moment and a high axial load into the structure
  - In consequence, a highly dynamic loading is applied onto the flanges connecting the compressor and bearing casing



Dynamic load

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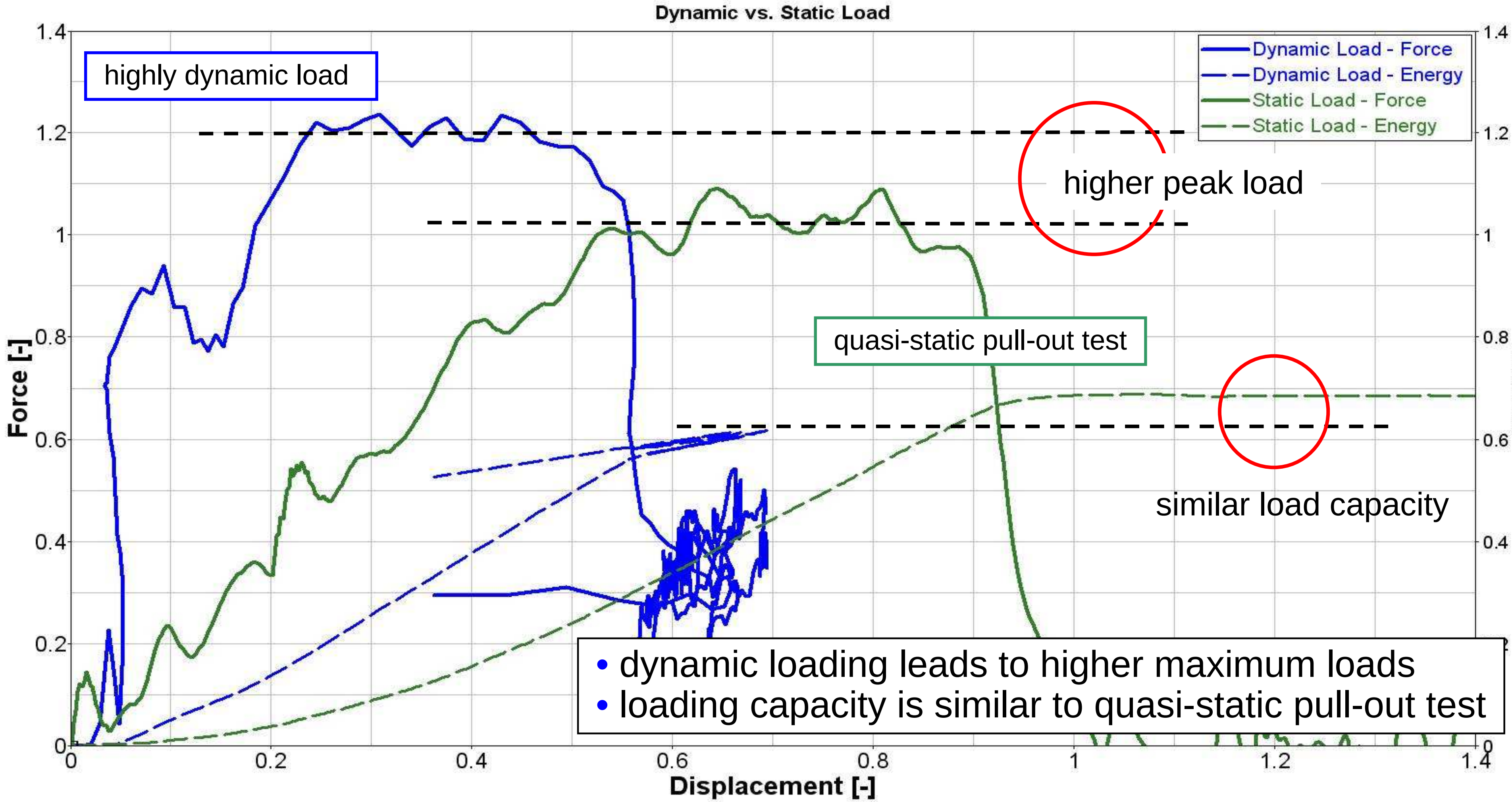
- Clamping ring under high dynamic loading



- dynamic loading leads to higher maximum loads
- loading capacity is similar to quasi-static pull-out test

Dynamic load

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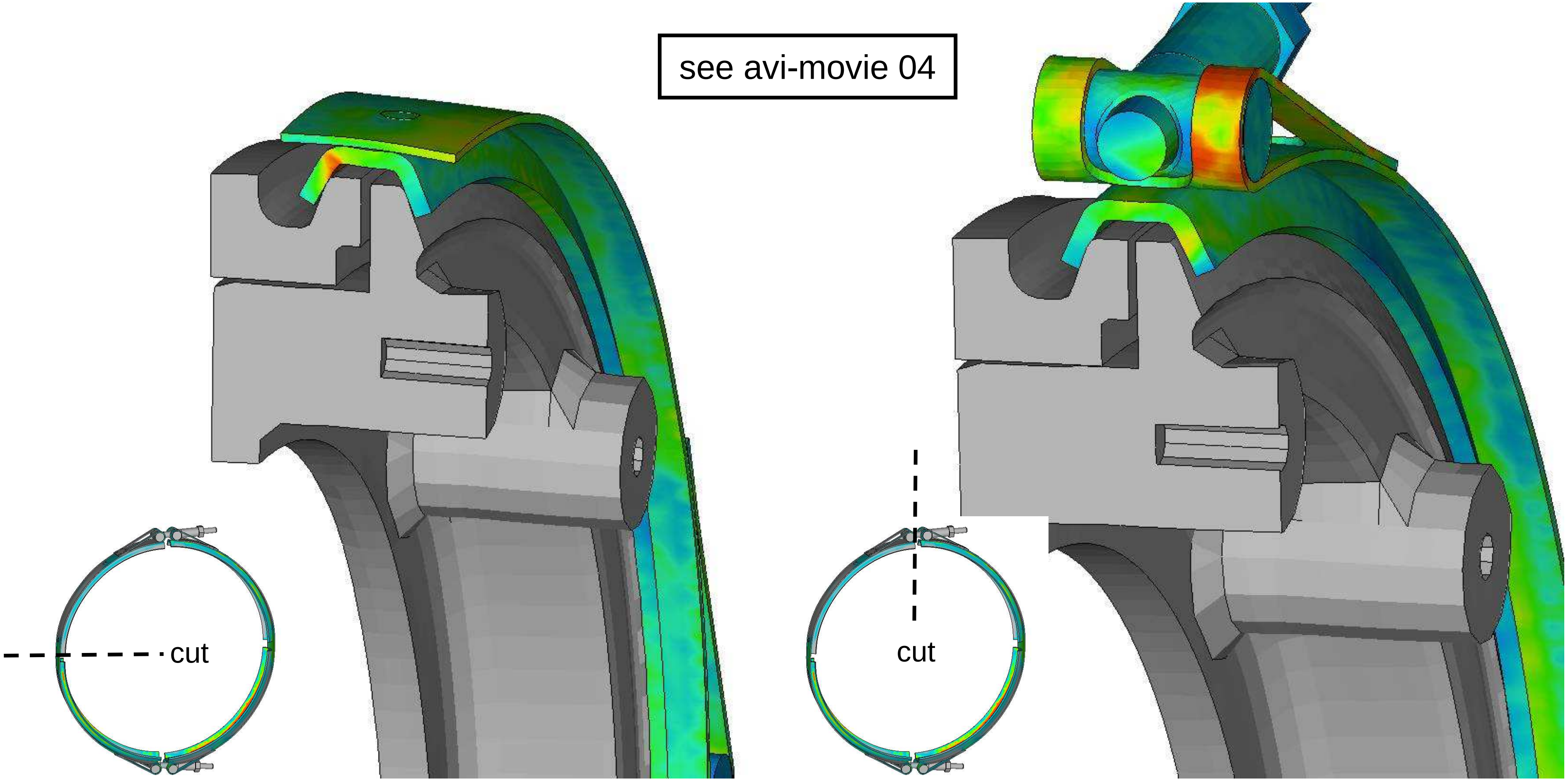
- Clamping ring under highly dynamic loading
  - Good balance of clamping ring and flange structure

see avi-movie 04



Dynamic load

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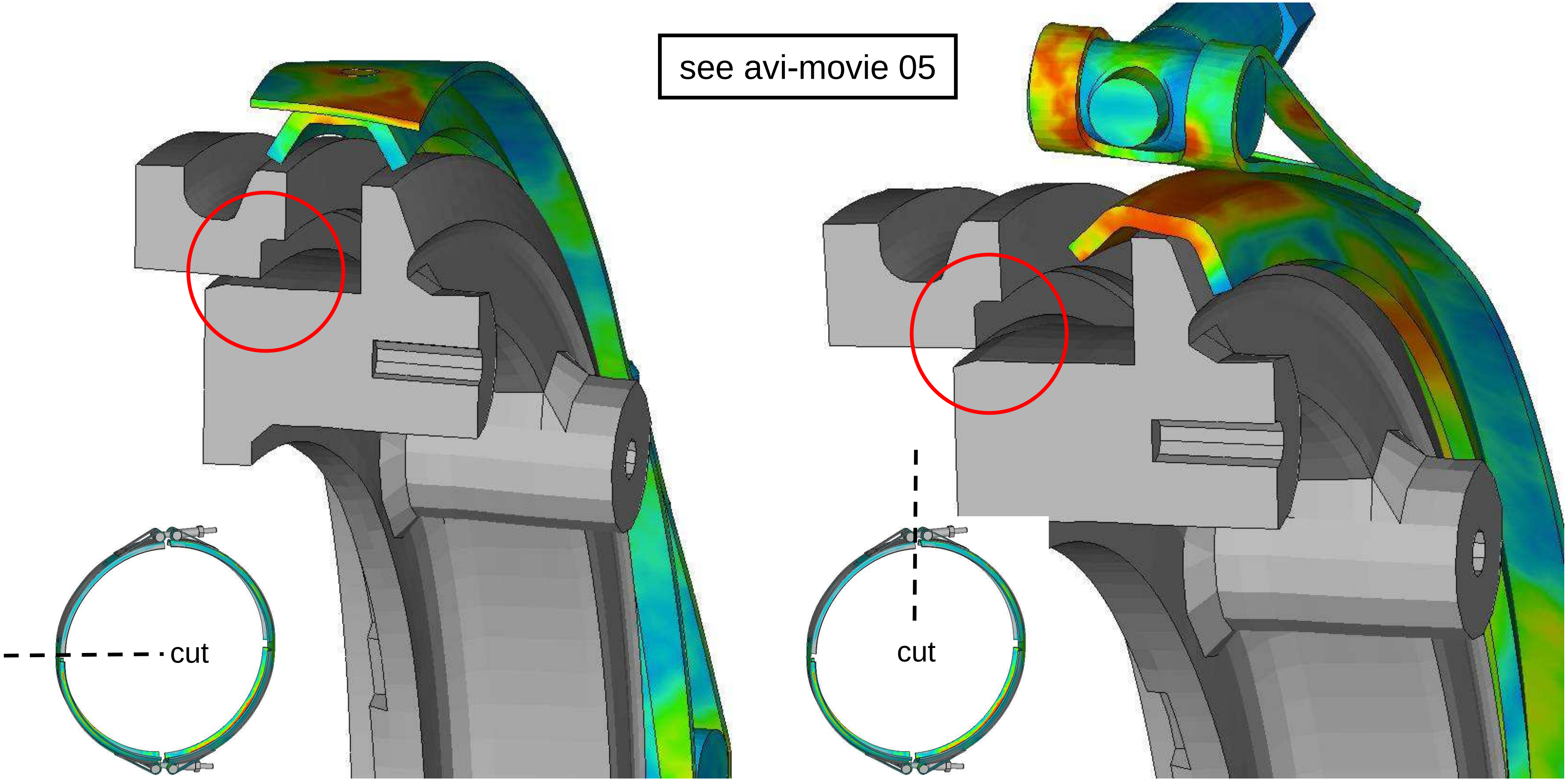
- Example of a stiffness mismatch
  - The clamping ring is too weak, the flange connection is lost

see avi-movie 05



Dynamic load

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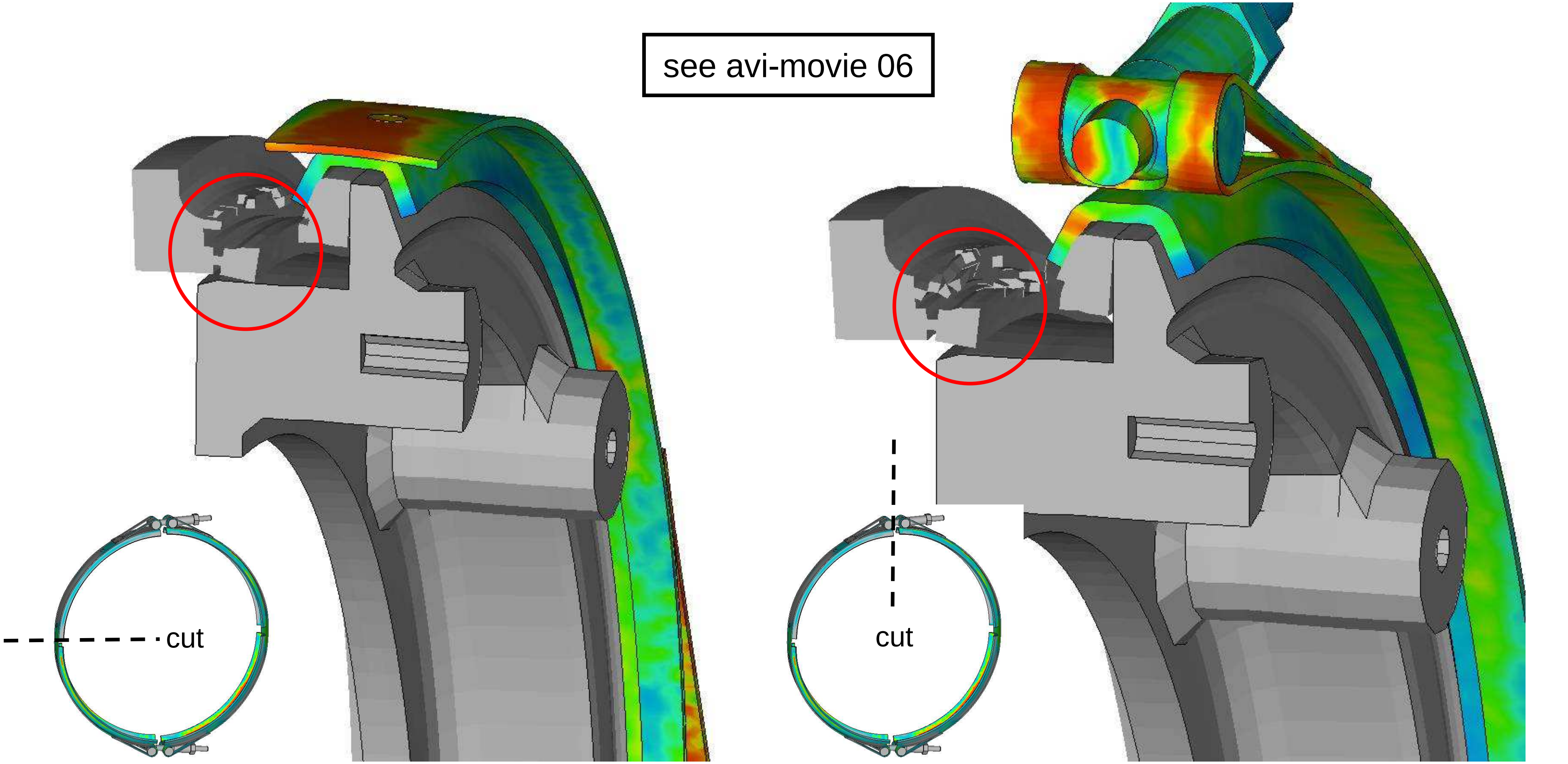
- Example of a stiffness mismatch
  - The clamping ring is too stiff, the flange fails, the connection is lost



Summary

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- Clamping ring design
  - For the worst-case scenario of an impeller burst, standard rules and static analyses for clamping ring design are no longer sufficient
  - The highly dynamic loading and non-linear effects in deformation, material behaviour and contact have to be taken into account
- CAE Simulation / Process
  - LS-DYNA Explicit is a very efficient tool for designing and optimising a clamping ring under highly loading,
    as well as for quasi-static simulations like the pull-out test shown
  - A validation of a quasi-static pull-out test was carried out in order to improve the reliability of the simulation prediction
  - The potential of the CAE optimisation was shown by a parameter study for quasi-static and highly dynamic loading

Summary

14th May 2009

- Acknowledgment
  - Many thanks to MTU Friedrichshafen GmbH
    - for the kind permission for using the pull-out test results
    - for the excellent teamwork with Dr. B. Koch and Dr. M. Vesper, Engineering Mechanics & Materials

- Please visit our booth
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