Simulation of a clamping ring under high dynamic loading

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Summary:

Clamping rings are used in a wide range of mechanical applications in order to assemble two or more cylindrical parts, e.g. tubes and pipes, pressure vessels and tanks. Another application area of clamping rings is in turbo engines, where they connect compressor, bearing and turbine casings for example.
For normal operating conditions, standard rules or simple static analyses are adequate to determine the relevant design parameters of this device. But these analyses are not sufficient for highly dynamic loading as in case of misuse or failure, e.g. shock waves, compressor surge and in particular the impeller burst. In these cases the loading of the clamping ring is no longer static nor linear. The impulse transmitted and the mass inertia of the parts connected play an essential role for the loading scenario. In addition the non-linear material behaviour, the high geometric deformation and plastification up to material failure as well as the complex contact situation have to be taken into account. For these extensive analyses explicit simulations using LS-DYNA have proven to be a highly efficient tool.
This presentation gives an overview on how to use CAE simulation for designing a clamping ring for highly dynamic loading. As a first step in the process described, a quasi-static pullout test is used to achieve a high correlation between hardware testing and simulation. The paper also gives an idea of the influences of some typical design parameters of a clamping ring, e.g. wall thickness and numbers of segments of the v-shaped lower strap. A focus of the development needs to be on the balance of structural stiffness of the clamping ring for one thing and the flanges of the parts connected for another. The presentation concludes by showing a successful simulation using LS-DYNA Explicit for the highly loaded clamping ring due to an impeller burst.

Keywords:

LS-DYNA Explicit, quasi-static and high dynamic loads, clamping ring, tubes and pressure vessels, pullout test, turbo engines, turbo charger, impeller burst, containment

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Simulation of a clamping ring under high dynamic loading

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Overview

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

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Introduction

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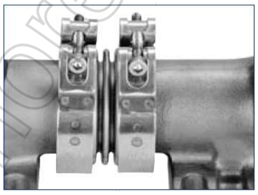
- Use of clamping rings
  - Connection of two or more parts at the cylindrical flanges

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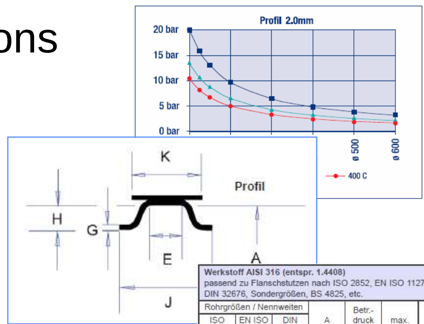
- Design for normal operating conditions
  - Standard rules and supplier guide lines
  - Simple static analyses



Werkstoff AISI 316 (entspr. 1.4408) passend zu Flanschstutzen nach ISO 2852, EN ISO 1127, DIN 32676, Sondergrößen, BS 4825, etc.						
Rohrgrößen / Nennweiten						
ISO 2852 (Zoll)	EN ISO 1127 (NW)	DIN 32676 (DN)	A in mm	Betr.-druck in bar bei 150° C	max. Test-druck	Gewicht in g
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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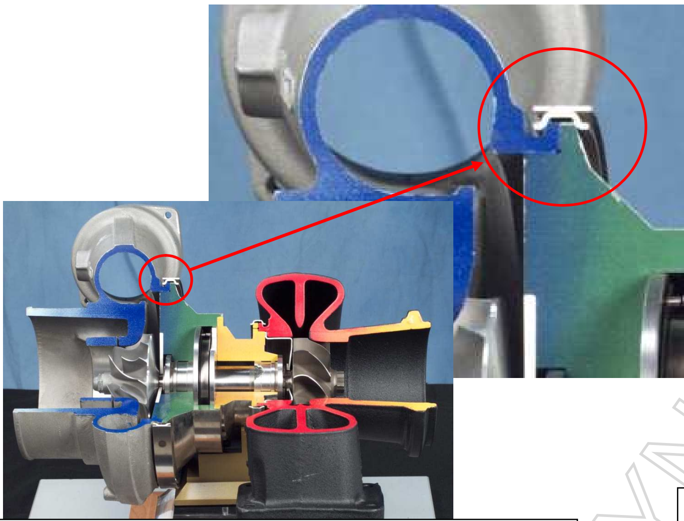
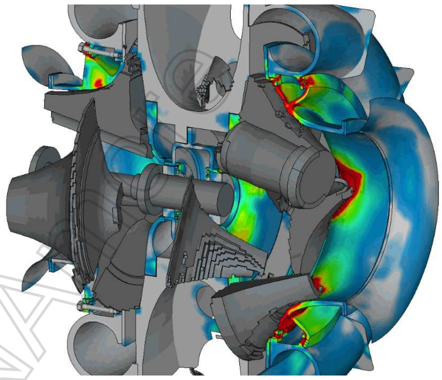
- Examples: Use of clamping rings in turbo engines

see avi-movie 01



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



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

CAE Process

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- CAE challenges for the highly dynamic loading
  - Significance of impulse transmitted due to the incident (gas/parts)
  - Significance of the mass inertia of the interacting parts
  - Non-linear material behaviour with dynamic strain rate effects and material plastification up to failure
  - High geometric deformation
  - Complex contact situation

- Use of LS-DYNA Explicit
  - Using LS-DYNA Explicit allows to meet these CAE challenges
  - LS-DYNA Explicit may also be used for quasi-static simulations (Keeping in mind some restrictions)

CAE Process

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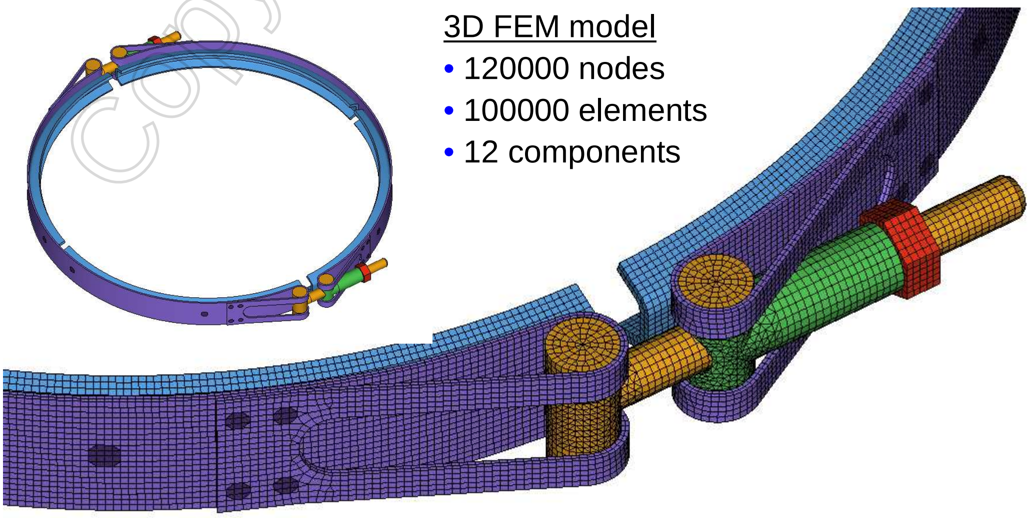
- CAE model technique
  - Typical CAE model of a clamping ring for crash simulation



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

Pull-Out Test

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- 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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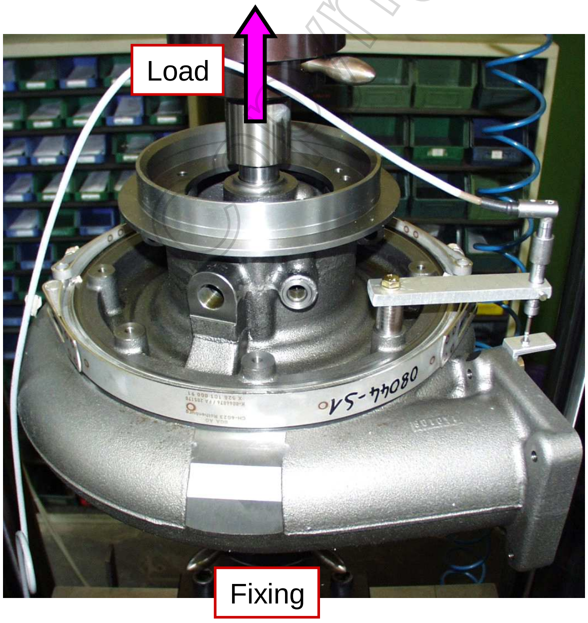
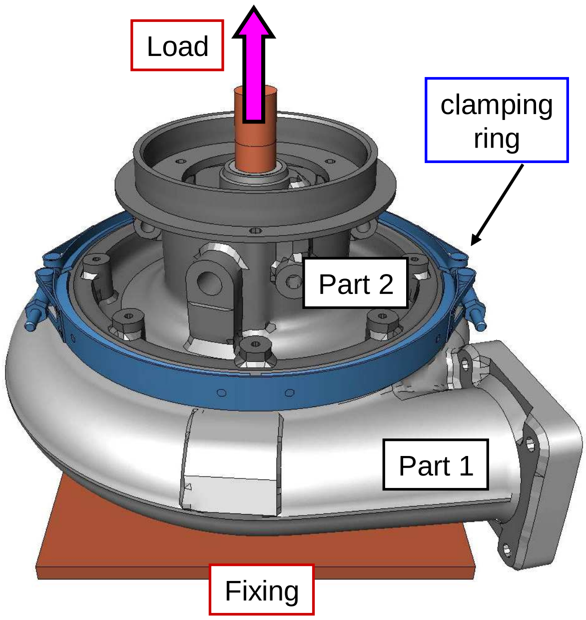
- Test ring in trial and in simulation





Pull-Out Test

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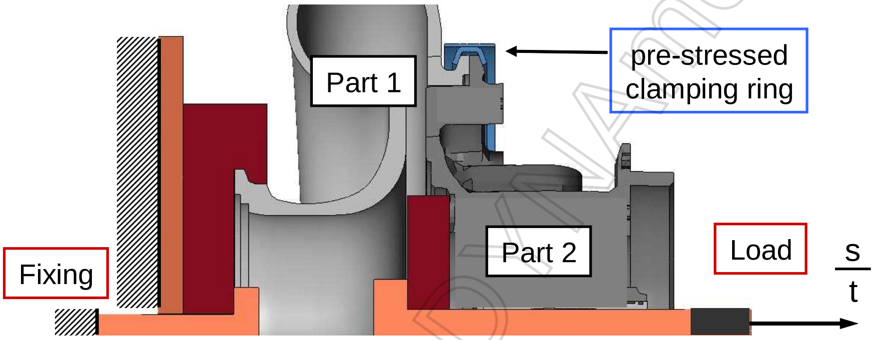
- Build up of the test rig
  - The compressor casing (part 1) is fixed in a seating
    - The seating is fixed on the ground plate of the test rig
  - The bearing casing (part 2) is loaded by a plunger
    - Quasi-static loading with prescribed displacement vs. time
  - The pre-stressed clamping ring connects part 1 and part 2



Pull-Out Test

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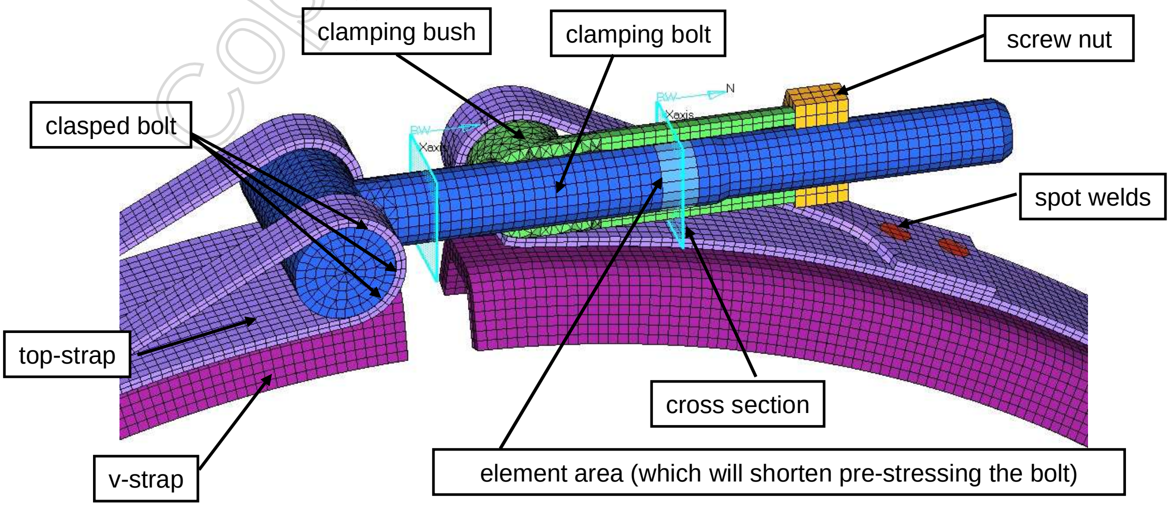
- CAE technique of the pre-stressed clamping ring
  - 3D model of the clamping ring using brick and tetra elements only



Pull-Out Test

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- CAE technique for pre-stressing the clamping ring
  - Initialisation by pre-stressing the bolts within the first 0.5ms only
  - Pre-stressing the clamping bolts in LS-DYNA by using
    - *INITIAL_STRESS_SECTION and *DEFINE_CURVE
    - *DATABASE_CROSS_SECTION_PLANE_ID

cross section for pre-stressing

```
$===========================
*INITIAL_STRESS_SECTION
$---1----|----2----|----3----|----4----|-
$    issid     csid     lcid     psid
      4102     4102    14102     4102
$-----------------------------------------
*DEFINE_CURVE
$---1----|----2----|----3----|----4----|-
$     lcid      sfa      sfo      sfr
     14102        0    1.000    1.000
$                  ai                 oi
            0.0000000          0.0000000
            0.1000000          0.0700000
            0.2000000          0.0900000
            0.3000000          0.1000000
            0.5000000          0.1000000
            0.6000000          0.0000000
           10.0000000          0.0000000
$-----------------------------------------
$
```

load curve for pre-stressing

```
$=======================================================================
*DATABASE_CROSS_SECTION_PLANE_ID
$---1----|----2----|----3----|----4----|----5----|----6----|----7----|-
$     csid
      4201
$---1----|----2----|----3----|----4----|----5----|----6----|----7----|-
$     psid      xct      yct      zct      xch      ych      zch
      4201   364.00   174.00      0.0   364.00   174.00      1.0
$     xhev     yhev     zhev     lenl     lenm       id    itype
    365.25   174.00      0.0     14.0     16.0        0        0
$---1----|----2----|----3----|----4----|----5----|----6----|----7----|-
$
*SET_PART_LIST
$---1----|----2----|----3----|----4----|----5----|----6----|----7----|-
$      sid      da1      da2      da3      da4
      4201
$     pid1     pid2     pid2     pid3     pid4     pid5     pid7
    405010
$---1----|----2----|----3----|----4----|----5----|----6----|----7----|-
$
```

part used for pre-stressing

Pull-Out Test

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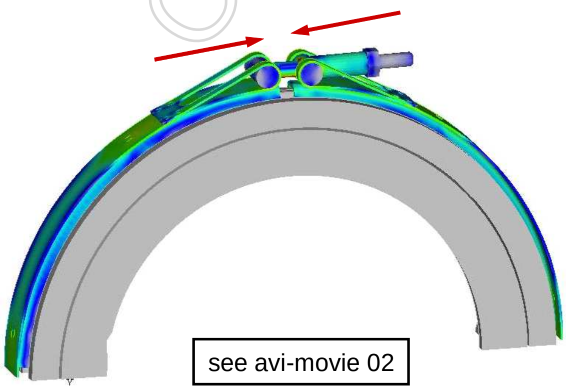
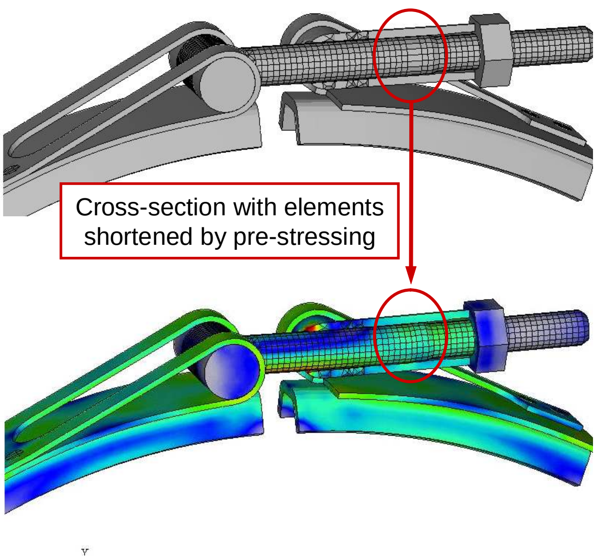
- CAE technique for pre-stressing the clamping ring
  - Pre-stressing of the bolts is realized by shortening the elements at the cross-section





Pull-Out Test

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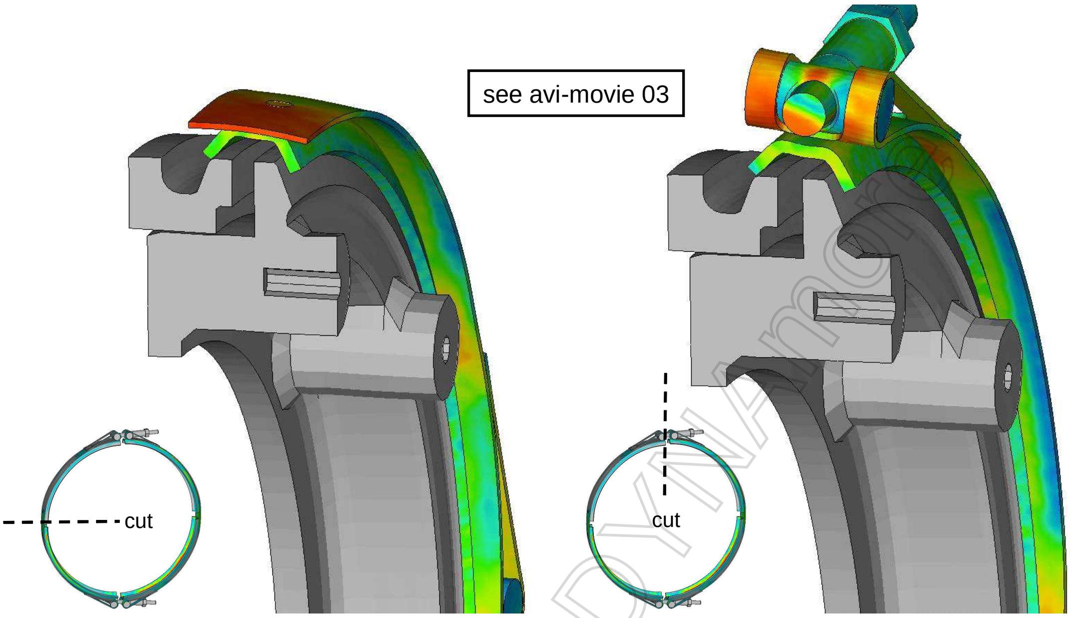
- Quasi-static pull-out test in simulation



Pull-Out Test

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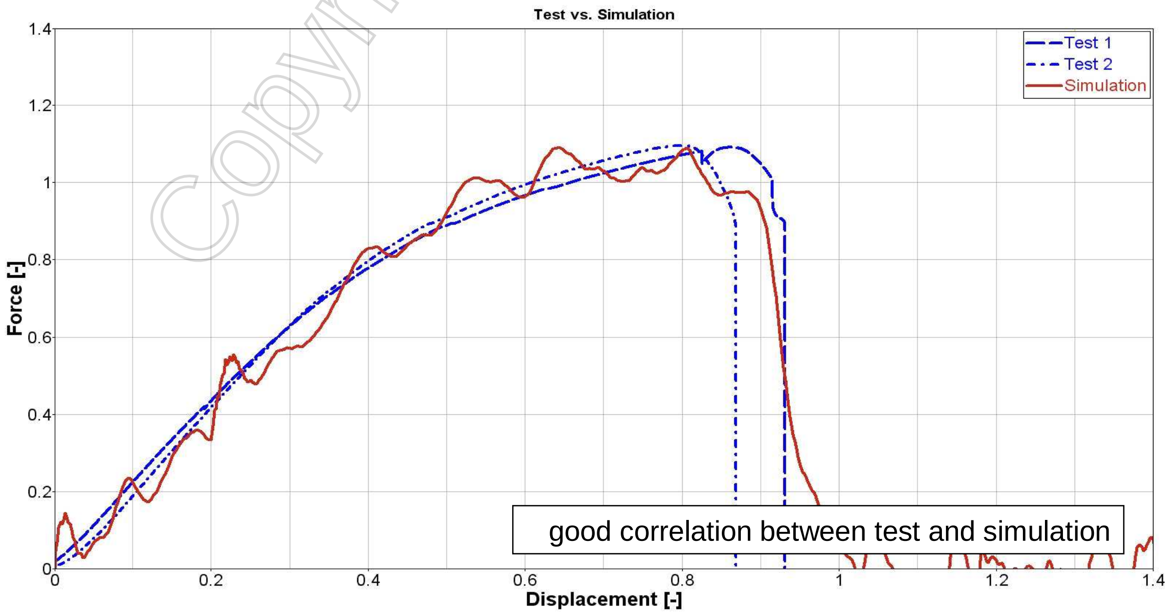
- Quasi-static pull-out test in simulation and trial



Pull-Out Test

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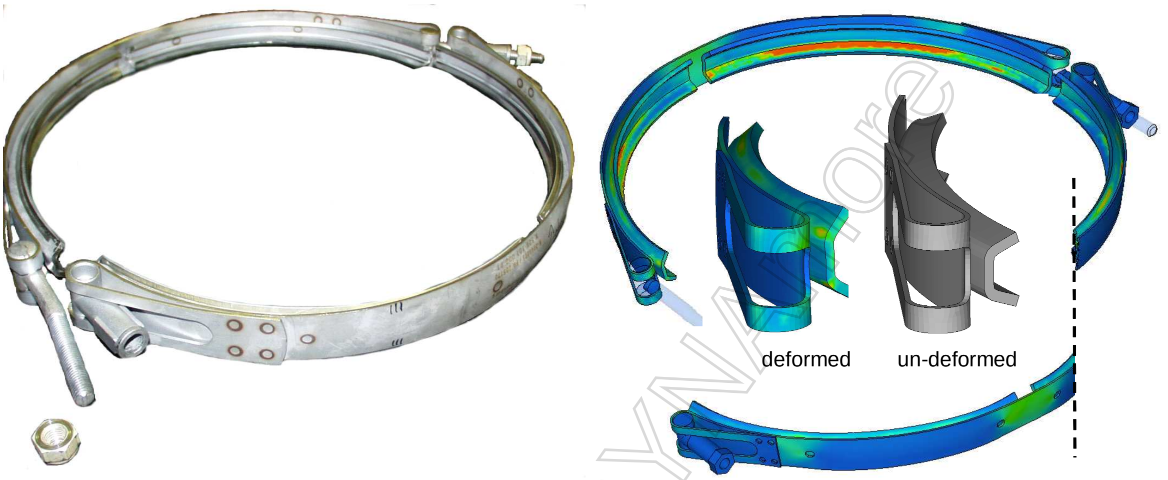
- Quasi-static pull-out test in simulation and trial
  - Good correlation between test and simulation



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
  - The pull-out test is done at the rather low speed of 1mm/min
  - Normally explicit codes are used for high speed and high deformation in a short time frame
  - In addition, within limits LS-DYNA Explicit can be used for simulating low speeds and nearly quasi-static loading, too
- Restrictions
  - The application of the load should be a compromise of the simulation time and a minimum of the dynamic effects
  - Convergence of the results should be checked by 3 or 4 steps
  - Taking these restrictions into account, LS-DYNA Explicit is a reasonable and stable simulation tool for quasi-static loading also

Pull-Out Test

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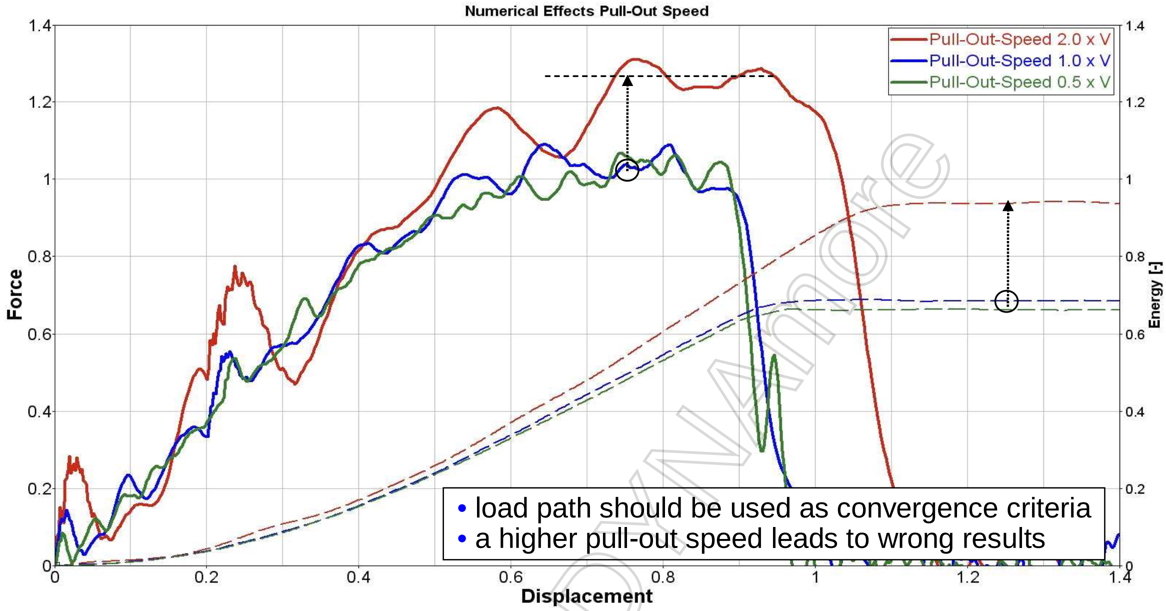
- Use of LS-DYNA Explicit for quasi-static analysis



Parameters

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- Introduction
  - The 2nd CAE task is a <u>parameter analysis</u> 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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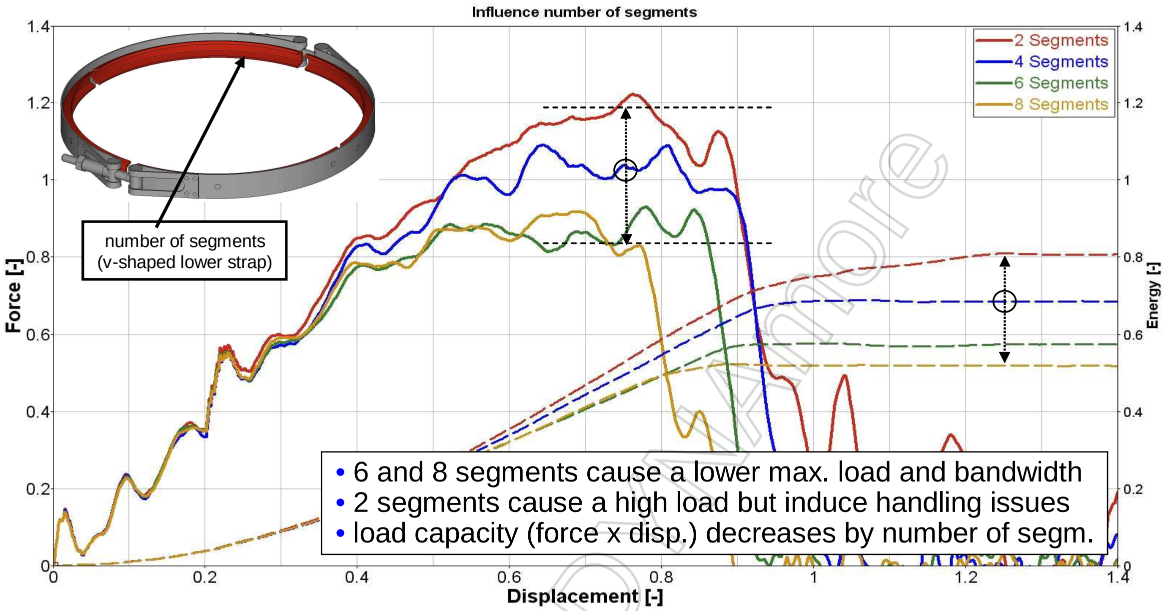
- Influence of the <u>number</u> of the segments of the <u>lower strap</u>



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Parameters

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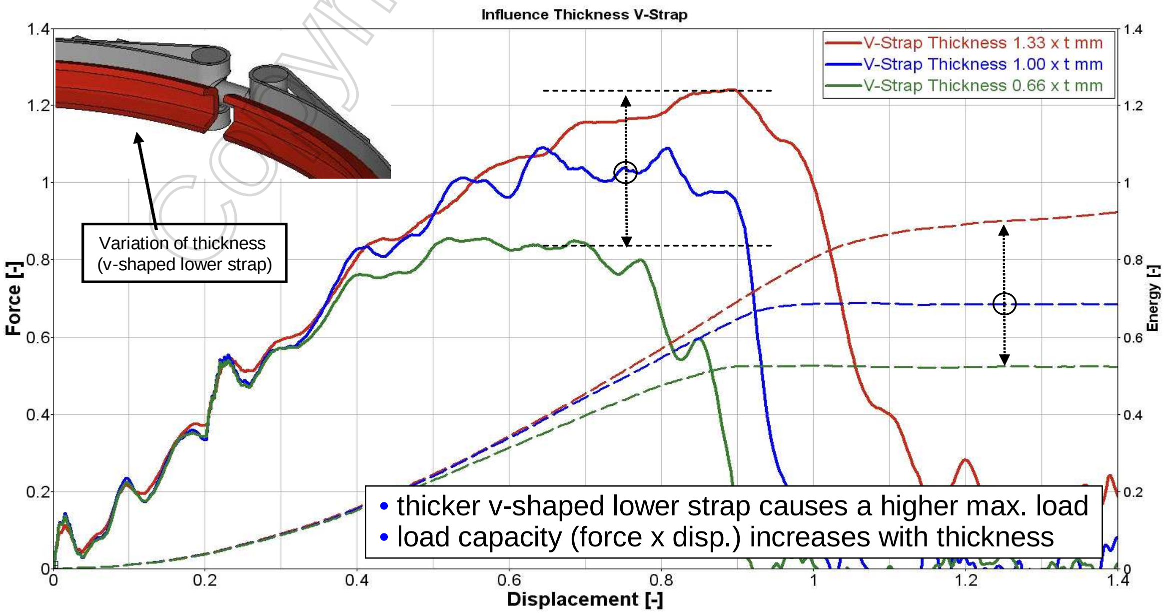
- Influence of the <u>thickness</u> of the v-shaped <u>lower strap</u>



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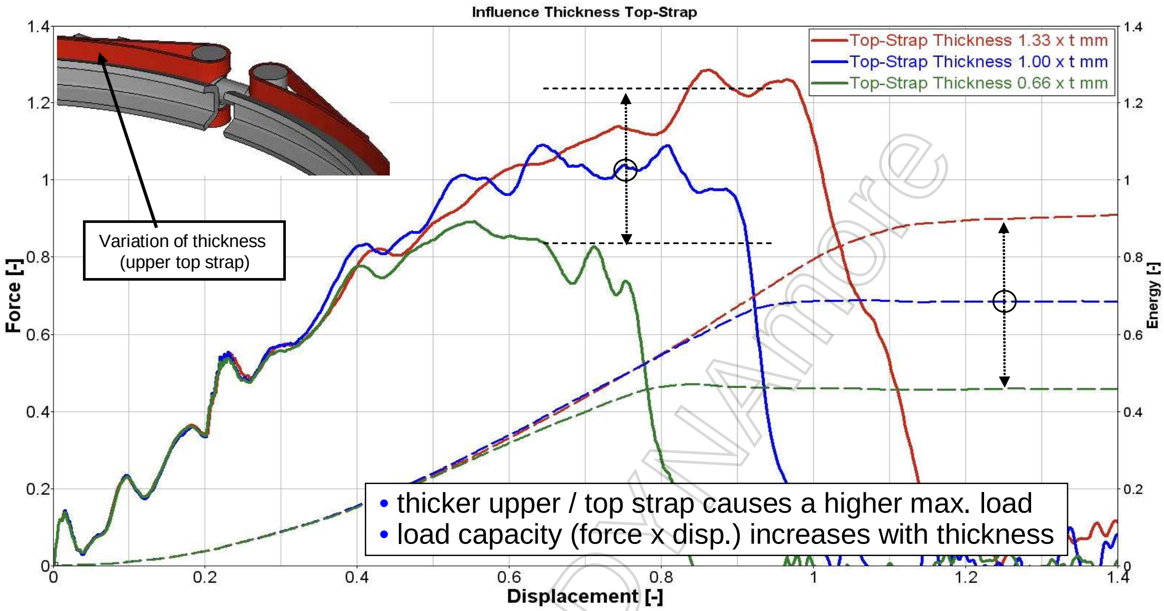
Parameters

- Influence of the thickness of the upper top strap



Parameters

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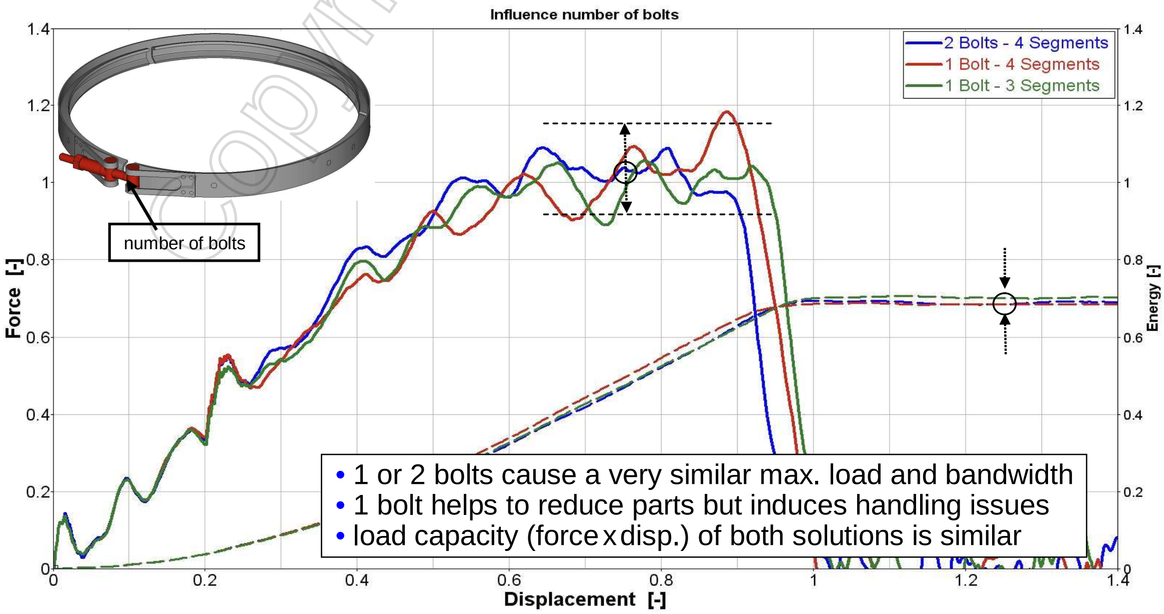
- Influence of the number of the bolts of the clamping ring



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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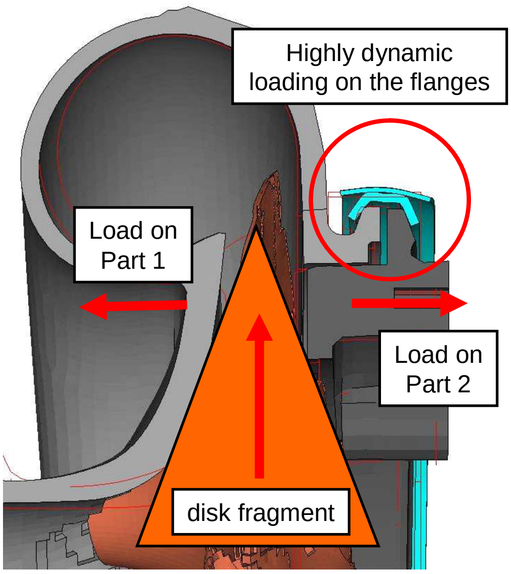
- Containment load case due to the impeller burst
  - Failure of the impeller (compressor wheel) releases a high amount of energy and impact load
  - The disk fragments move radially entering the airflow channel towards the casing spiral
  - Acting like wedges, they introduce a high bending moment and 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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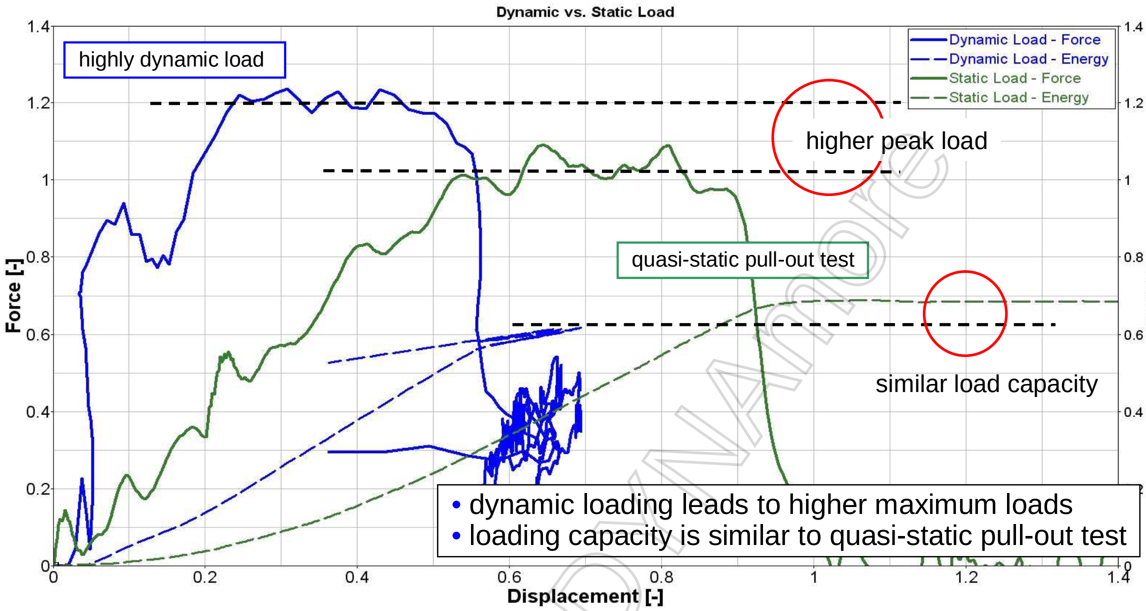
- Clamping ring under high dynamic loading



Dynamic load

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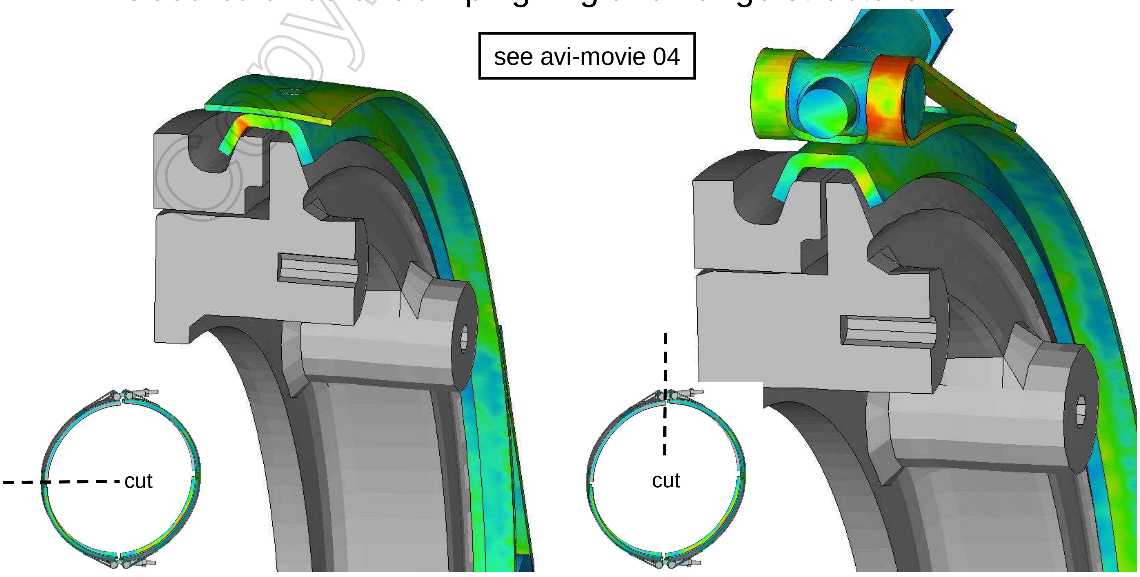
- Clamping ring under highly dynamic loading
  - Good balance of clamping ring and flange structure



Dynamic load

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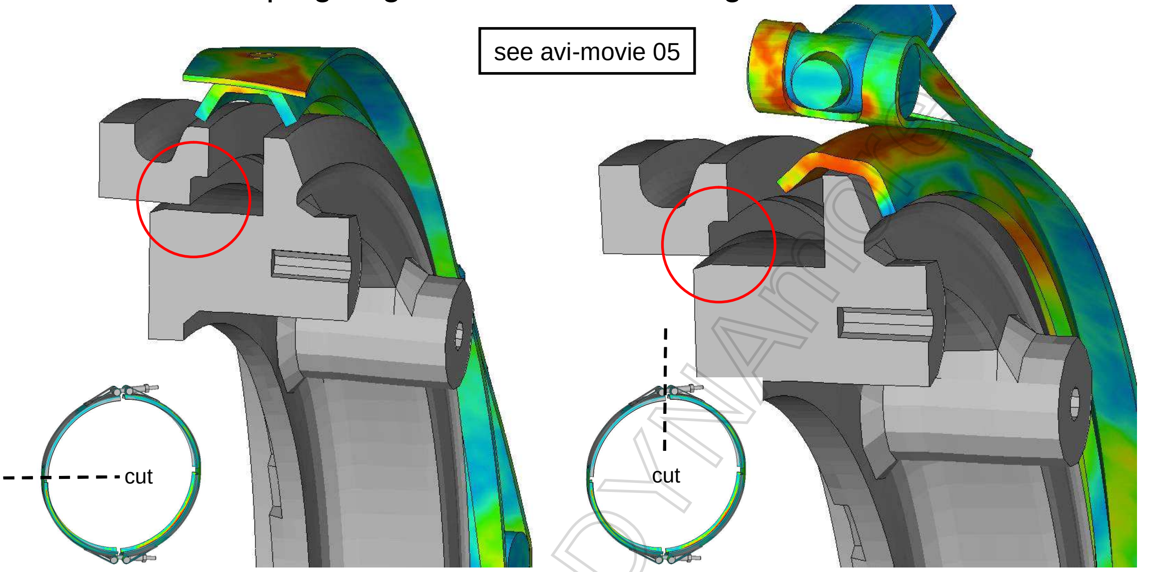
- Example of a stiffness mismatch
  - The clamping ring is too weak, the flange connection is lost



Dynamic load

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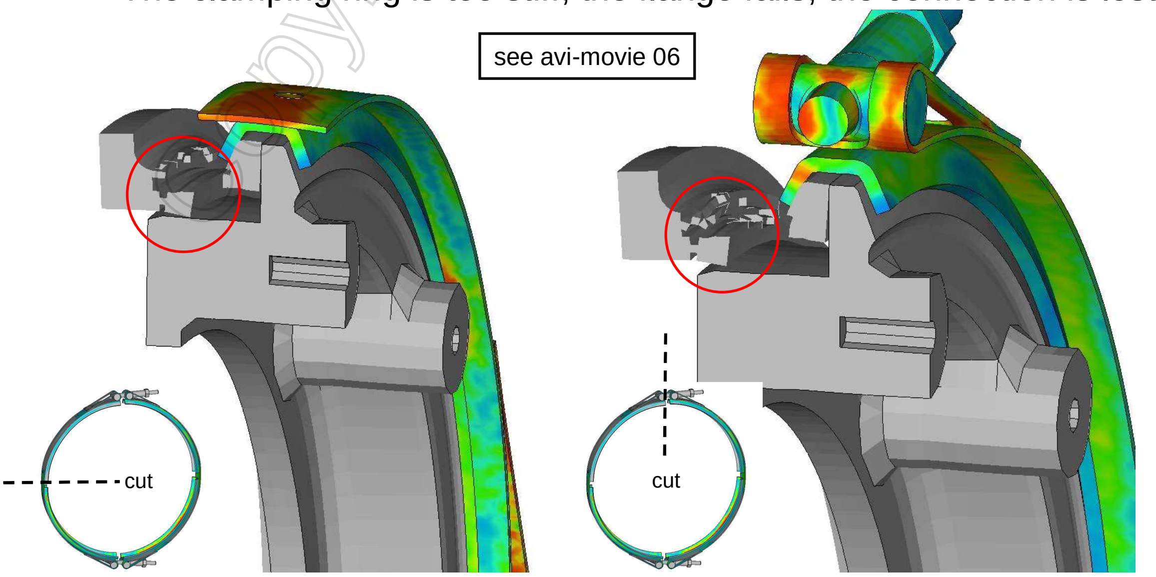
- Example of a stiffness mismatch
  - The clamping ring is too stiff, the flange fails, the connection is lost



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
  - 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

Appendix

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
- References of pictures
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