Simulation of a clamping ring under high dynamic loading

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Overview

• 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

• 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

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

- 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

Examples: Use of clamping rings in turbo engines

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

see avi-movie 01
CAE Process

• **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
  • 1\(^{st}\) task: a quasi-static pull-out test to validate the CAE technique
  • 2\(^{nd}\) task: a parameter analysis of the clamping ring (optionally for better knowledge of essential design parameters)
  • 3\(^{rd}\) task: the burst simulation meaning the highly dynamic loading
Pull-Out Test

• 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

- Test ring in trial and in simulation
Pull-Out Test

- 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

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

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

see avi-movie 02

Cross-section with elements shortened by pre-stressing
Pull-Out Test

- Quasi-static pull-out test in simulation

see avi-movie 03
Pull-Out Test

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

Test vs. Simulation

good correlation between test and simulation
Pull-Out Test

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

significant plastic deformation of v-shaped lower strap
Pull-Out Test

Use of LS-DYNA Explicit for quasi-static analysis

- load path should be used as convergence criteria
- a higher pull-out speed leads to wrong results
Parameters

- Introduction
  - The 2\textsuperscript{nd} 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

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

- 6 and 8 segments cause a lower max. load and bandwidth
- 2 segments cause a high load but induce handling issues
- Load capacity (force x disp.) decreases by number of segm.
Parameters

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

- Thicker v-shaped lower strap causes a higher max. load
- Load capacity (force x disp.) increases with thickness
Parameters

- **Influence of the thickness of the upper top strap**

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

- 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

- 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

- Clamping ring under high dynamic loading

Dynamic vs. Static Load

- Highly dynamic load
- Higher peak load
- Quasi-static pull-out test
- Similar load capacity

- Dynamic loading leads to higher maximum loads
- Loading capacity is similar to quasi-static pull-out test
Dynamic load

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

see avi-movie 04

cut
Dynamic load

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

see avi-movie 05

cut
Dynamic load

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

see avi-movie 06
Summary

• 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

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