An ALE-formulation for dual mortar finite deformation contact problems with wear

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Introduction

Wear due to frictional contact
- Complex phenomena characterized by loss of material at contact surfaces
- One of the main causes for component damage and subsequent failure of machines and devices [1]
- High relevance in biomechanical applications, e.g. for joint prostheses [2]

Aim of this work
- Prediction of structural failure due to wear
- Consideration of different wear types with changing underlying physical effects, such as abrasive-, adhesive-, corrosive- and fretting-wear

Structure-ALE approach

Aspects of continuum mechanics
- Shape evolution due to wear is directly modeled
- Time dependent reference configuration which is called material configuration
- Consideration of wear only on mortar-slave surface (one-body wear)

Staggered structure-ALE algorithm
1. Calculate standard frictional mortar contact with holding the material displacements constant (Lagrangian step)
2. Determine wear in spatial configuration by employing nodal quantities from (1)
3. Solve Eulerian step in spatial configuration with calculated wear as Dirichlet boundary condition
4. Map resulting spatial nodal positions to material configuration (Advection map)

Configurations of slave body:
- Material configuration
- Spatial configuration
- Solution of wearless contact problem (cf. (1))
- Additional wear displacements (cf. (2))

Arbitrary Lagrangean-Eulerian - ALE

Employing fractional step method [4] as decoupled solution procedure:
1. Pure Lagrangean step
2. Pure Eulerian step

- ALE-formulation is used as an auxiliary structure
- Purely Dirichlet-based Eulerian step to relocate the positions of nodes within the slave-body
- At least one surface of the body has to be fixed for the Eulerian step
- Preventing degeneration of nodes when accumulated wear displacements are larger than element thickness [5]

Advection map
- The last step in the structure-ALE algorithm is well-known as Advection Map problem
- Based on employing the isoparametric properties of the Finite Element Method

1. Find the parameter space coordinate $\xi$ by solving
   $\sum_{i=1}^{n} N_i(\xi) x_i - \tilde{x}_j = 0$
2. Calculate material displacements with
   $\tilde{d}_{ij} = \mathbf{N}(\tilde{\xi}_j) \cdot (X^{\text{ele}} - X^{\text{ref}})$

Material configuration
- Spatial configuration
- Reference configuration

Results

Oscillating 2D block on cylinder
- Elastic beam is pressed onto a rigid cylinder [5]
- 5 Sinusoidal horizontal slidings
- Visualised normal contact tractions decreasing due to ongoing wear removal
- Simulation is done within 530 timesteps (53s)

Oscillating 3D block on sphere
- Rigid block is pressed onto an elastic sphere
- 5 Sinusoidal horizontal slidings
- Constant vertical displacement of the block
- Relatively coarse mesh with 370 Hex8 elements
- Simulation is done within 530 timesteps (53s)

Conclusions

- Wear modeled as stress-free displacements resulting in macroscopic structural effects
- Included wear variationally consistent as additional gap in constraint condition
- Embedded wear theory into the existing dual mortar framework
- Prevented element degeneration with Eulerian phase

Outlook
- Calculation of wear on both interacting bodies
- Consideration of wear on critical geometries, e.g. edges and corners
- Developing interaction of wear and thermomechanical effects

References