



Elements and splines for contact problems with large slidings

B. Magnain^a, A. Batailly^b, N. Chevaugneon^c, M. Legrand^b, C. Pierre^b

(a) Institut PRISME
ENSI Bourges

(b) Structural dynamics and
vibration laboratory
McGill University

(c) GéM, UMR CNRS 6183
Pôle calculs et structures
École Centrale de Nantes



Problem description

hal-006657382, version 1-6 Jan 2012

Contact problems are highly nonlinear and may lead to complex and inefficient simulations

In particular, high sensitivity of contact simulations when **large slidings** occur on curved contact interfaces

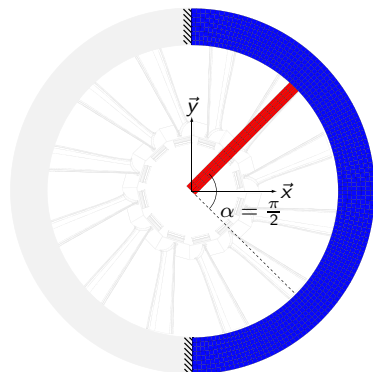
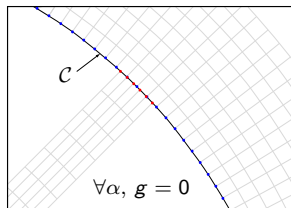
- **discontinuity** of the orientation of the normal to the contact surface (*facetization*)
- non smooth **approximation** of the gap function
- **mesh refinement** may not be a solution when large models are involved

Practical manifestation

hal-00657382, version 1 - 6 Jan 2012

rotor/stator interaction study may lead to the simulation of permanent contact between a blade and the surrounding casing

- rubbing
- modal interaction



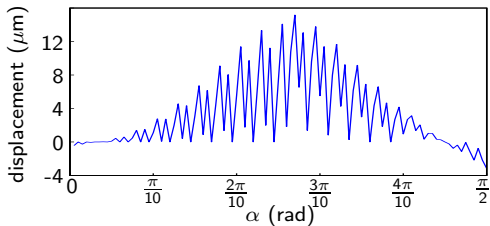
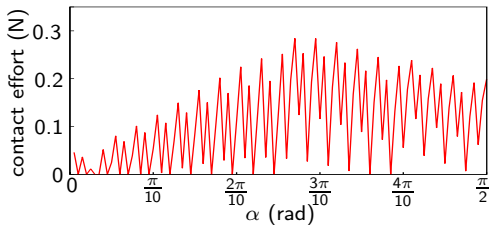
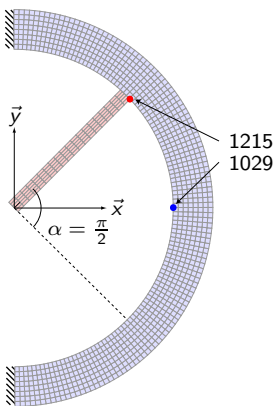
Contact detection results from discretization errors

Practical manifestation

hal-00657382, version 1 - 6 Jan 2012

Beam: Q4 (20×5)

Ring: Q4 (120×8)



Layout

hal-00657382, version 1 - 6 Jan 2012

1 Introduction

- Problem description
- Practical manifestation

2 C^1 —continuous methods:Hermite and B-splines

- Description
- Gap inaccuracy
- Contact normal orientation approximation
- Contact detection

3 Large slidings cases

- validation case:cube and rings
- blade tip/casing

4 Conclusion

C^1 -continuous methods

Objective: better representation of a curved contact surface

Means:

- mortar elements
- superposition of linear elements and smoothing methods (B-splineS)
- integration of smoothing methods within the element (Hermite element)

Focus of our study: compare B-spline and Hermite methods that are compatible with our solution algorithm.

B-splines

Description:

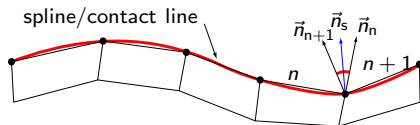
- third degree polynomial basis
- interpolation splines: control points chosen in agreement with mesh

Assets:

- Independent on the element type of the mesh
- can be easily extended to 3D cases

Requirements:

- specific detection procedure with Newton-Raphson method
- higher computation time



Hermite finite element

Description :

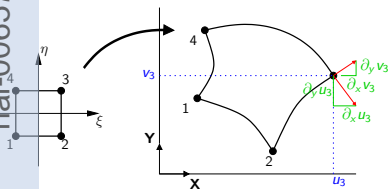
- 24 dof isoparametric element with cubic edge
- dof include coordinates of tangent vector to the edges

Assets :

- continuity of normal vector orientation from an element to another
- automatic update of the contact surface with mesh deformation

Requirements :

- specific mesh construction
- higher computation time



$$\mathbf{u}_i = \left\{ u_i, \frac{\partial u_i}{\partial x}, \frac{\partial u_i}{\partial y}, v_i, \frac{\partial v_i}{\partial x}, \frac{\partial v_i}{\partial y} \right\}$$

$$i = (1, 2, 3, 4).$$

C^1 —continuous methods: validation

hal-006657382, version 1 - 6 Jan 2012

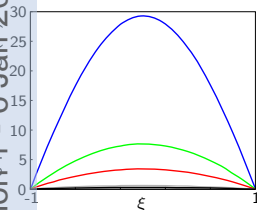
The pertinence of each strategy is assessed by:

- 1 checking **geometrical errors**
 - ▶ gap inaccuracy
 - ▶ contact normal orientation approximation
- 2 validating **contact detection**
- 3 simulating **large sliding** contact cases

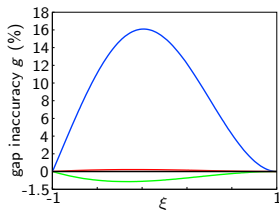
All the simulations presented are quasi-static simulations without friction using bi-potential method for contact management in total Lagrangian framework.

Gap inaccuracy

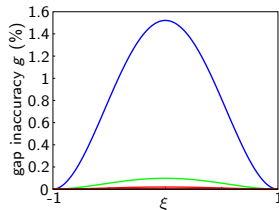
hal-00657382, version 1, 6 Jan 2012



a) Linear discretization

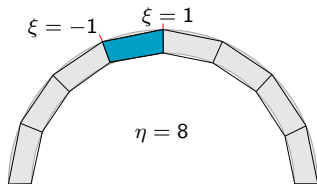
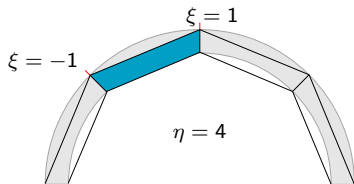


(b) Spline discretization



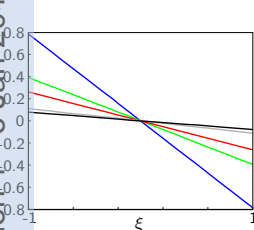
(c) Hermite discretization

gap inaccuracy for $\eta = 2$ — blue; $\eta = 4$ — green; $\eta = 8$ — red; $\eta = 14$ — grey and $\eta = 20$ — black, η being the number of elements over the $\frac{1}{2}$ ring.

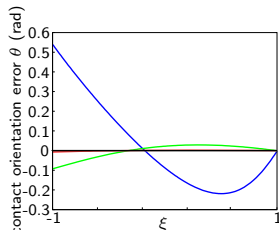


Contact normal orientation approximation

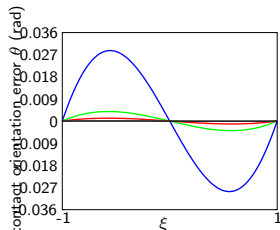
hal-00657382 version 16 Jan 2012



d) Linear discretization

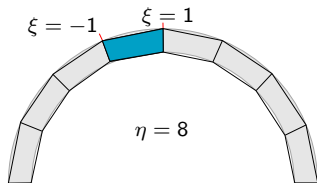
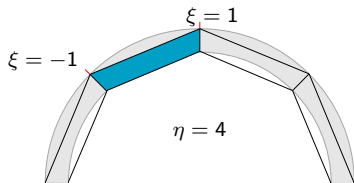


(e) Spline discretization



(f) Hermite discretization

contact orientation error for $\eta = 2$ — blue —; $\eta = 4$ — green —; $\eta = 8$ — red —; $\eta = 14$ — grey — and $\eta = 20$ — black —.



Contact normal orientation approximation

hal-00657382, version 1 - 6 Jan 2012

Both the addition of B-spline over linear elements and the use of Hermite elements allow for significant improvements of the **gap inaccuracy** and the **contact normal orientation error**.

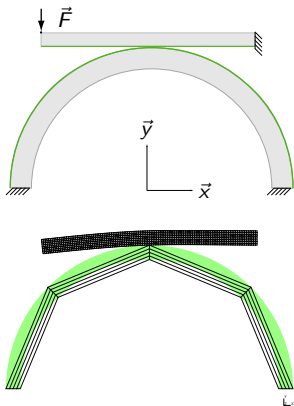
The choice of the mesh parameters for our study is driven by the following conditions:

- maximum gap error must be $g_{\max} < 1\%$ of the outer radius of the ring
- convergence must be observed for static simulations (sensitive bending of structures modeled with Q4 elements)

Mesh parameters: 10×8

Contact detection

Assessment of contact detection: beam in contact over a $\frac{1}{2}$ ring, flexible or rigid.

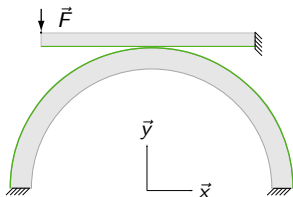


- Load applied on the tip of the beam.
- maximum displacement is equal for the three discretization methods
- no penetration detected

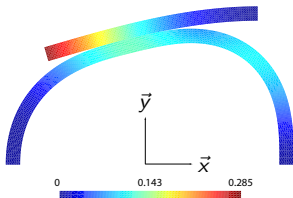
Good contact detection

Contact detection

Assessment of contact detection: beam in contact over a $\frac{1}{2}$ ring, flexible or rigid.



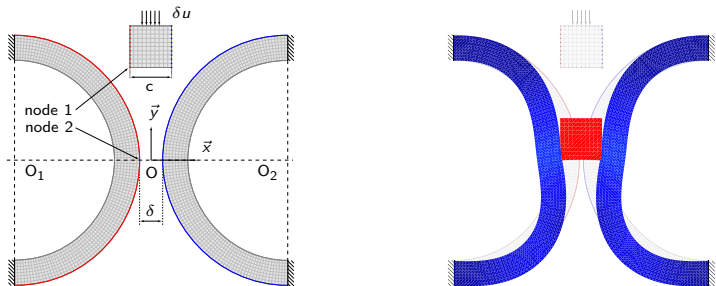
(loading)



Large slidings: cube and rings

hal-00657382, version 1 - 6 Jan 2012

Contact simulation with large slidings is first tested in the following situation:

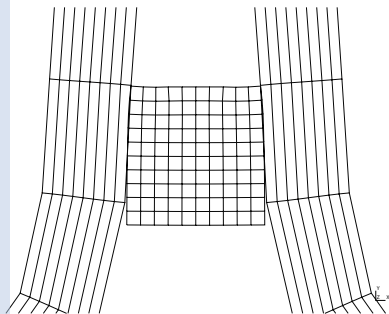


- Forced displacements on the superior edge of the cube
- Two distinct contact areas
- Symmetric contact case

Large slidings: cube and rings

hal-00657382, version 1 - 6 Jan 2012

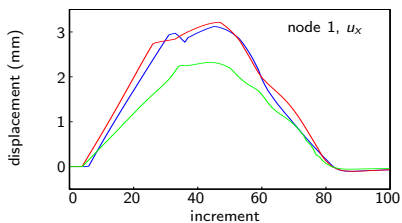
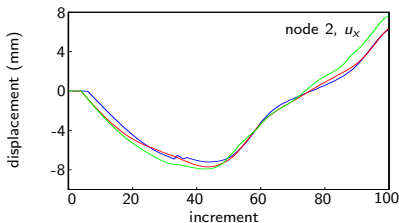
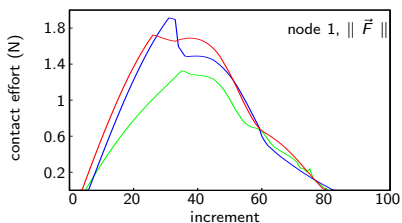
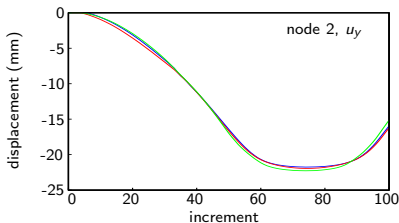
Contact simulation with large slidings is first tested in the following situation:



(loading)

Large slidings: cube and rings

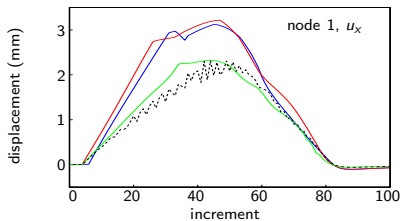
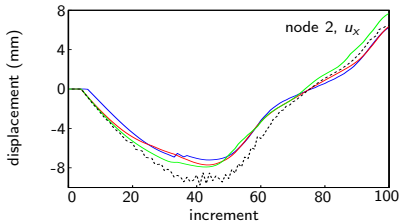
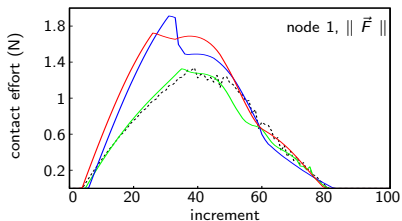
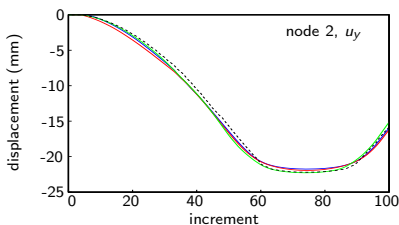
hal-00657382, version 1 - 6 Jan 2012



linear finite elements — blue —, B-splines on linear finite elements — red —, Hermite elements — green —

Large slidings: cube and rings

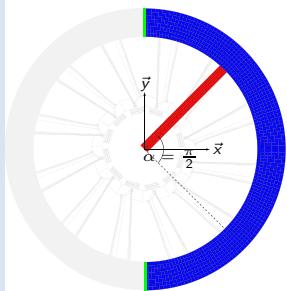
hal-00657382, version 1 - 6 Jan 2012



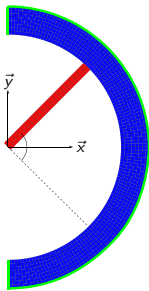
linear finite elements —, B-splines on linear finite elements —, Hermite elements — and refined mesh with linear finite elements - -

Large slidings: blade/casing

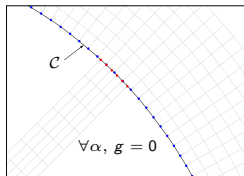
mentioned in the introduction, the contact cases are:



case 1



case 2



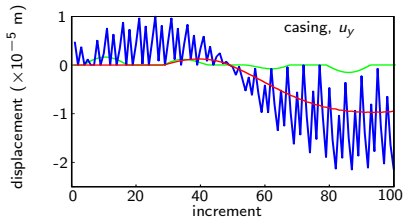
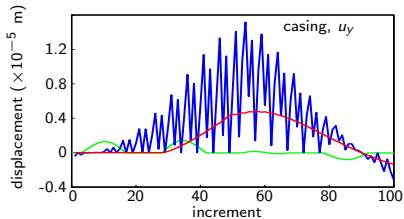
- case 1: the $\frac{1}{2}$ ring is clamped on its extremities
- case 2: the $\frac{1}{2}$ ring is clamped on its extremities and for $R = R_e$

Mesh of the ring is 120×8 for linear elements and 10×8 for Hermite elements.

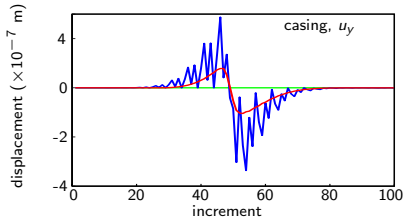
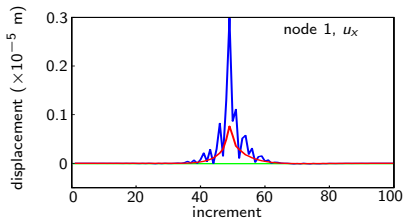
Large slidings: blade/casing, results

hal-00657382, version 1 - 6 Jan 2012

case 1:



case 2:

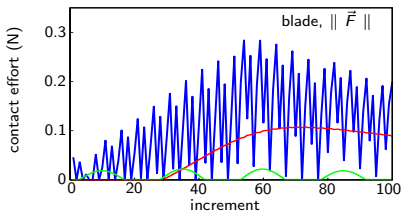


linear finite elements —, B-splines on linear finite elements —, Hermite elements —

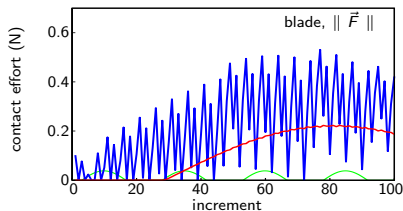
Large slidings: blade/casing, results

hal-00657382, version 1 - 6 Jan 2012

case 1:



case 2:



linear finite elements —, B-splines on linear finite elements —, Hermite elements —

Large slidings: blade/casing, mesh size influence

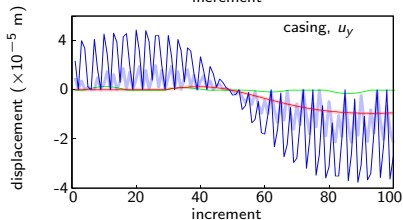
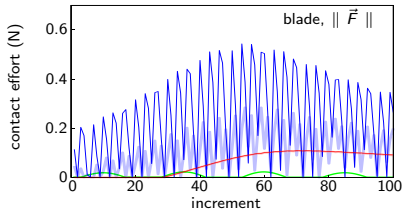
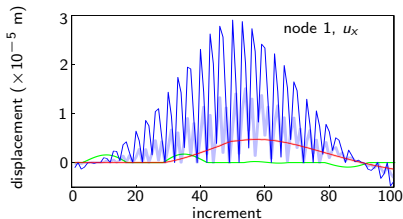
hal-00657382, version 1 - 6 Jan 2012

- Previous results show the smoothing obtained with the use of a B-spline over linear finite elements
- Facetization and discretization errors phenomenon obviously depends on mesh size
- Smoothing methods' sensitivity to mesh size (?)

mesh $120 \times 8 \Rightarrow$ mesh 60×4

Large slidings: blade/casing, mesh size influence

Case 1: (similar results are obtained for case 2)



linear finite elements — blue —, B-splines on linear finite elements — red —, Hermite elements — green —

Conclusion

- B-splines and Hermite elements allow for an important reduction of geometrical errors
- Both methods ensure contact normal orientation continuity
- It has been shown that when large slidings occur, discontinuous displacements and efforts appear due to discretization errors
- Using a smoothing method not only allow for the suppression of these discontinuities but may also allow for mesh size reduction
- In 2D, Hermite elements allow for a significant diminution of the number of dof

future work:

- Dynamic simulations must be carried out to highlight the consequences of displacements and efforts discontinuities
- 3D simulations on industrial models
- .

hal-00657382, version 1 - 6 Jan 2012