UTILIZATION OF THE POLYGONAL CONTACT MODEL FOR THE SIMULATIONS OF THE TILES MOVING THROUGH A KILN

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Main aim

To develop the computational model suitable for the numerical simulations of the tiles moving through a kiln by means of ceramic rollers.

Talk outline

- Introduction and problem description
- Modelling using standard contact elements (FE18 approach)
- About the polygonal contact model (PCM)
- Utilization of the polygonal contact model
- Conclusion and comparison with LS-Dyna software
Introduction

▶ ŠKODA VÝZKUM s.r.o. (ŠKODA RESEARCH Ltd.)
  ▶ Former part of ŠKODA HOLDING company (transportation, energy)
  ▶ Hundred years of the research in Pilsen (1907 – 2007)
  ▶ Today → standalone research and testing company (computer-aided modelling, fluid mechanics, mechanical and dynamical testing laboratories, noise and vibration, . . . )

▶ Multibody dynamics in ŠKODA VÝZKUM s.r.o.
  ▶ SIMPACK, alaska, in-house software (MATLAB)
  ▶ Vehicle dynamics (trolleybuses, buses, rail vehicles), biomechanics, special problems (nuclear engineering – control assemblies, tiles, . . . )
Introduction

▶ HOB Cer Tec s.r.o.

▶ Czech producer of ceramic rollers

▶ Rollers are used in modern kilns in order to transport ceramic tiles through a kiln

▶ Numerical simulations of the tile movement in a kiln were requested
Introduction

- Kilns can be very long (100 – 150 meters)
- Various rollers (with respect to the shape and flexibility), different tiles (with respect to dimensions and weight)
Introduction

Due to the production technology the rollers can be of a conical shape

Owing to cooling in vertical position the lower end can be wider

Length \( l = 3.9 \text{ m} \), supported on the ends, outer diameter \( D = 0.052 \text{ m} \), inner diameter \( d = 0.04 \text{ m} \)
Problem description

- Tiles are transported by means of rollers in the rows (depending on the width of tiles)
- The reference velocity of tiles → 150 meters per hour (0.0417 m/s)
Problem description

- After the passage of the tiles through a kiln → the originally straight row of tiles becomes curved
- It is undesirable phenomenon for the kiln operators
Problem description

- Why does it happen?
- Is it caused by conical shape rollers?
- What parameters most influence the problem?

- Complex unusual mechanical system (many contacts, rollers flexibility, neglecting influence of temperature changes, ...)
Model based on the FE18 element

- **Multibody approach** can be suitable for the solution (in ŠKODA VÝZKUM limited to rigid bodies)

- **Contact modelling possibilities in SIMPACK**
  - The SIMPACK Contact module
  - Single point contact (moved markers, force elements)
  - Multipoint contact (FE45 – two separate curves)
  - Hertzian contact (FE222, ball, cylinder, plane)

- **Tiles and rollers** → multipoint contact, but FE45 not suitable

- **Solution** → set of moved markers + unilateral spring-damper elements (FE18)
Model based on the FE18 element . . .

- **Roller model (substructure)**
  - **Flexibility**: $N$ segments (rigid bodies), allowed bending (FE13, compared with FE model), closed loop (constraint)
  - **Rheonomic joint** on one end (defined angular velocity $\omega_{\text{roller}}$)
  - **Set of moved markers** for the contact definition (MM94, rotation)
Model based on the FE18 element . . .

- **Tile model** → one rigid body, 6DOF joint
- **Contact model** → moved marker + FE18 (unilateral spring-damper)
- **Friction force** (lateral direction), “driving” force (based on rolling condition) → FE50 (component force by expression)
Model based on the FE18 element . . .

▶ Many bodies and many contact elements —> automatic generator of SIMPACK source files (MATLAB, acronyms for element names, . . .)

▶ Results of the numerical simulations were not sufficient (not realistic enough due to the contact model, especially roller shape description, very long computational time due to the many force elements, . . .)

▶ Movies —>
About the polygonal contact model (PCM)

- Developed and implemented in SIMPACK by Dr. Gerhard Hippmann

- References


- Available in SIMPACK as the force determined by an user subroutine (The SIMPACK User Module is necessary)
About the polygonal contact model (PCM) . . .

- Contact algorithm for multibody dynamics (rigid bodies, very robust)
- Body surfaces are represented by polygonal meshes
  - Vertices and faces
  - Complex surfaces can be represented
  - PCM requires any duplicate vertices, any cracks, consistent orientation

Example of polygonal mesh (taken from [1])
About the polygonal contact model (PCM) . . .

- Contact forces are determined using the elastic foundation model
  - Bodies are covered by thin elastic layer, shear stress neglected
  - Contact forces are implemented using discretized contact surface (contact patch)

(taken from [1])
About the polygonal contact model (PCM) . . .

- **PCM algorithm** (see [1], [2])
  - Collision detection (based on bounding volume hierarchies, recursive algorithm, fast)
  - Contact element determination (intersection polygon → active area → contact elements)
  - Contact force determination (elastic + damping contact forces, regularized friction → total force and torque on bodies in contact)
Utilization of the polygonal contact model (PCM)

- **Roller model** (substructure)
  - Flexibility $\rightarrow N$ segments (rigid bodies), allowed bending (FE13, compared with FE model), closed loop (constraint)
  - Rheonomic joint on one end (defined angular velocity $\omega_{\text{roller}}$)
  - Roller segment *polygonal model* (automatic generation, . . . )
Utilization of the polygonal contact model (PCM) . . .

- **Tile model** → one rigid body, 6DOF joint, simple mesh
- **Contact model** → PCM user force (normal contact + friction)
- **Master surface (roller) / Slave surface (tile)**
- **One tile–roller segment pair** → one contact force
Utilization of the polygonal contact model (PCM) . . .

- Automatic generator of SIMPACK source files (MATLAB, . . .)
- Ideal rollers case simulated, only limited number of rollers
- SODASRT integrator
- Movies →

- The problem of “faster outer” tiles with respect to “inner” tiles was verified . . .
Introduction

FE18 Approach

About PCM

Utilization of PCM

Conclusion

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x-position of the left (outer) tile with respect to the chosen inner tiles

<table>
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<tr>
<th></th>
<th>X tile 8 - X tile 5</th>
<th>X tile 8 - X tile 6</th>
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For time [s] from 0.0 to 20.0, the graph shows the movement of the sensor position in meters, with values ranging from -1.00 to 0.75 x 10^{-3}.
Comparison of results obtained by LS-Dyna

▶ The same problem was verified also in LS-Dyna (explicit solver, FEM)

▶ LS-Dyna deals with short duration events → not so suitable for moving tiles (some improvements were necessary)
Comparison of results obtained by LS-Dyna ...
Conclusion

- Tiles transferred on ceramic rollers $\rightarrow$ unusual multibody system
  - Problem characterized by multiple complex contacts and flexibility of the rollers
- SIMPACK software were chosen for the solution
  - Standard contact elements (not so efficient)
  - Very robust polygonal contact model (acceptable results)
- The problem of “curved row of tiles” after moving through a kiln was found even for perfect rollers
- The model was prepared for other simulations (sensitivity analysis, . . .)
- This work was supported by the research plan MSM 4771868401 of the Ministry of Education, Youth and Sports of the Czech Republic