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FINITE ELEMENT/ MULTIBODY SYSTEM ALGORITHMS FOR RAILROAD VEHICLE SYSTEM DYNAMICS

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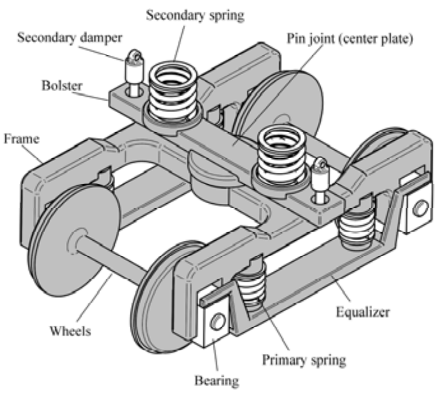
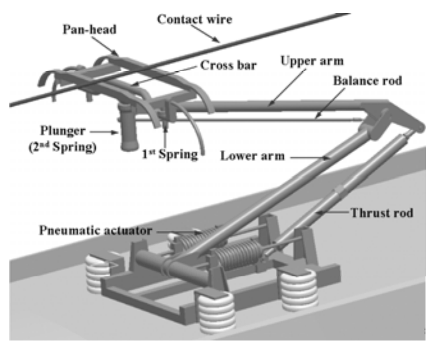
BACKGROUND

1. Railroad vehicles are examples of multibody systems (MBS); large rotations (nonlinearities), and algebraic equations (constraints).

2. General purpose MBS codes have DAE's solver, can be used to develop more detailed models, can handle more general simulation scenarios, do not employ linearization, and can be used for advanced flexible body investigations.

3. In order to correctly capture nonlinear effects in existing train models and future high speed rail systems, it is necessary to use MBS codes.





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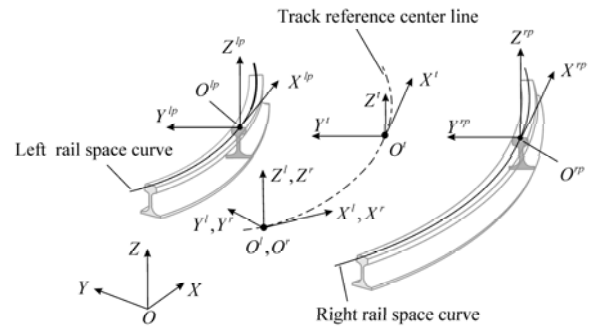
GOALS AND APPROACHES

1. Develop new general, 3-D fully nonlinear wheel/rail contact formulations that can be implemented in MBS algorithms (no linearization, no look-up tables, creep forces).
2. Develop rail module (SAMS/Rail) that can be linked to existing general purpose MBS codes (such as SAMS/2000) that have advanced flexible body modeling capabilities (track and rail flexibility, car body flexibility, etc).
3. Develop accurate methods for track geometry description (ANCF, B-Splines, curvature, super-elevation, grade).



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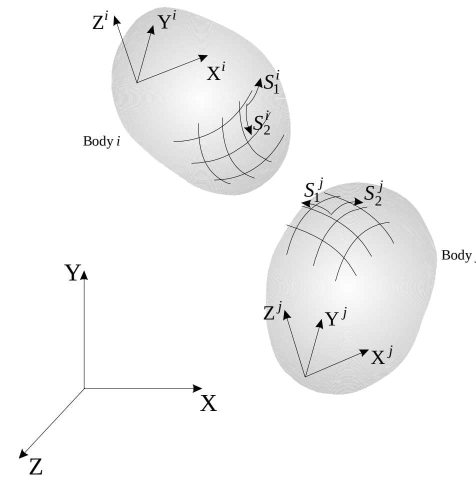
WHEEL/RAIL CONTACT FORMULATIONS

1. In contact constraint and elastic formulations, five equations are used.
2. Normal wheel/rail contact force is used with creepages in the calculations of the creep forces (hunting).
3. Higher derivatives with respect to the surface parameters must be evaluated.

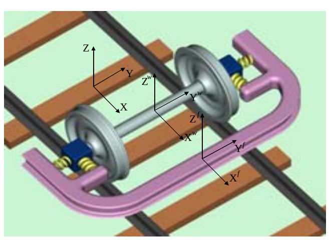


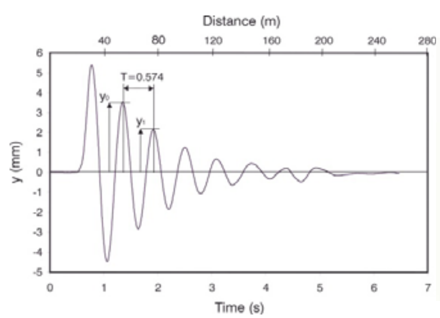
$$\mathbf{r}^i - \mathbf{r}^j = \mathbf{0}$$

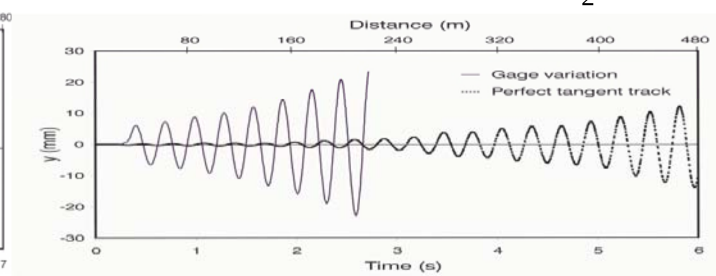
$$\mathbf{n}^{j^T} \mathbf{t}_1^i = 0$$

$$\mathbf{n}^{j^T} \mathbf{t}_2^i = 0$$

R. Yakoub, D. Valtorta, K. Zaazaa







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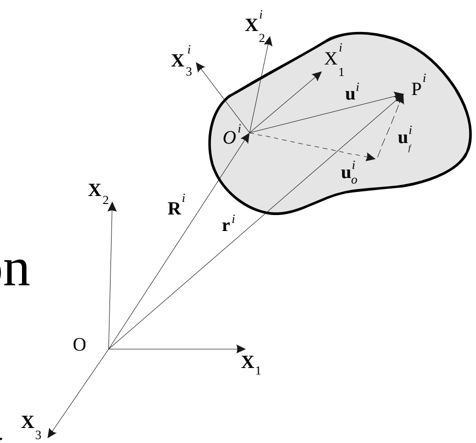
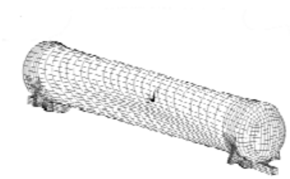
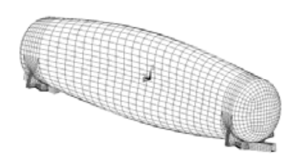
FLEXIBLE BODY DYNAMICS

- **Floating Frame of Reference (FFR)**
  - Large translation and rotation
  - Systematic coupling of FE/MBS codes
  - Use of modal analysis for coordinate reduction
  - Implemented in general purpose MBS codes



- **Flexible Rail Model (Integration of Geometry and Analysis)**
  - **Geometry**: Isoparametric ANCF representation for the rail surface is used to determine higher derivatives of the geometric vectors.
  - **FFR/FE deformation analysis**: Detailed track models can be developed by integrating FE/MBS algorithms (cross ties, fasteners, ballasts, etc.).





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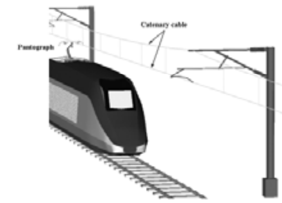
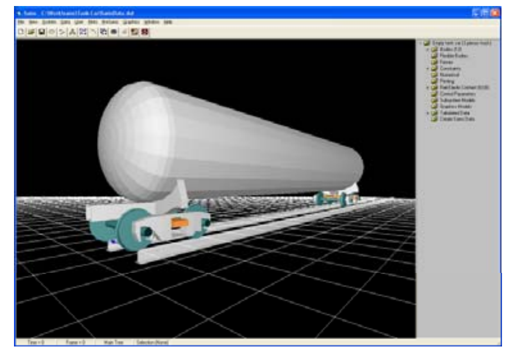
MBS SPARSE MATRIX IMPLEMENTATIO

- SAMS/2000 is designed to solve systems that consist of rigid bodies ($\mathbf{q}_r$), flexible bodies ($\mathbf{q}_r$, $\mathbf{q}_f$), and very flexible bodies ($\mathbf{q}_a$).
- All the system constraints, including contact constraints, are satisfied at the position, velocity and acceleration levels.
- The user has access to all elements of the equations of motion.

M. Berzeri



J.H. Seo



G. Sanborn

System Coordinates

$$\mathbf{q} = \begin{bmatrix} \mathbf{q}_r^{\mathrm{T}} & \mathbf{q}_f^{\mathrm{T}} & \mathbf{q}_a^{\mathrm{T}} & \mathbf{s}^{\mathrm{T}} \end{bmatrix}^{\mathrm{T}}$$

Constraints

$$\mathbf{C}(\mathbf{q}_r, \mathbf{q}_f, \mathbf{q}_a, \mathbf{s}, t) = \mathbf{0}$$

$$\mathbf{C}_{\mathbf{q}_r}\ddot{\mathbf{q}}_r + \mathbf{C}_{\mathbf{q}_f}\ddot{\mathbf{q}}_f + \mathbf{C}_{\mathbf{q}_a}\ddot{\mathbf{q}}_a + \mathbf{C}_{\mathbf{s}}\ddot{\mathbf{s}} = \mathbf{Q}_c$$

Augmented Equations

$$\begin{bmatrix} \mathbf{M}_{rr} & \mathbf{M}_{rf} & \mathbf{0} & \mathbf{0} & \mathbf{C}_{\mathbf{q}_r}^{\mathrm{T}} \\ \mathbf{M}_{fr} & \mathbf{M}_{ff} & \mathbf{0} & \mathbf{0} & \mathbf{C}_{\mathbf{q}_f}^{\mathrm{T}} \\ \mathbf{0} & \mathbf{0} & \mathbf{M}_{aa} & \mathbf{0} & \mathbf{C}_{\mathbf{q}_a}^{\mathrm{T}} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{C}_{\mathbf{s}}^{\mathrm{T}} \\ \mathbf{C}_{\mathbf{q}_r} & \mathbf{C}_{\mathbf{q}_f} & \mathbf{C}_{\mathbf{q}_a} & \mathbf{C}_{\mathbf{s}} & \mathbf{0} \end{bmatrix} \begin{bmatrix} \ddot{\mathbf{q}}_r \\ \ddot{\mathbf{q}}_f \\ \ddot{\mathbf{q}}_a \\ \ddot{\mathbf{s}} \\ \boldsymbol{\lambda} \end{bmatrix} = \begin{bmatrix} \mathbf{Q}_r \\ \mathbf{Q}_f \\ \mathbf{Q}_a \\ \mathbf{0} \\ \mathbf{Q}_c \end{bmatrix}$$

SUMMARY

1. MBS algorithms that employ DAE's solver and sparse matrix techniques are necessary for accurate virtual prototyping of railroad vehicle systems.
2. Several three-dimensional wheel/rail contact formulations are implemented in SAMS/Rail. The locations of the contact points are predicted online.
3. The track geometry is defined using ANCF finite elements that allow for accurate calculations of the position coordinates and geometric vectors at the wheel/rail contact points.
4. Flexible body FE/MBS algorithms are integrated to study the track, car body and vehicle component deformations.

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Thank You!

Australia, November 28, 2003; 48 cars.
Cause; heat-Induced track buckle.