Motivation

- Commercial multibody system simulation (MBS) codes mainly use modeling strategies based on a redundant set of coordinates.
- Unnecessary degrees of freedom (DOFs) are introduced easily through kinematic relations.
- Constraint equations which address kinematic chains or unstressed DOFs are typically introduced.
- Repetitive simulations (parameter identification, optimal control, optimal input design, ...) use Nashguluer et al. (2012), suffer from such possible inefficiencies.
- We reduce such a highly redundant set of coordinates by eliminating physical and constraint DOFs, using Proper Orthogonal Decomposition (POD).

Reduction Method (A Case Study in [5])

Model reduction is not a possible input but needs at least one full system forward simulation to test out. The model reduction process is based on the following assumptions and conditions:

Physical DOF reduction

- The POD process is based on the flow fields, which address linear and rotational velocities in the singular value decomposition (SVD).
- Proper Orthogonal Decomposition (POD) and Mode shapes (POD) are generated independently for translational and rotational DOFs using singular value decomposition:

\[ X = \Phi \Sigma W^T \]

(2)

- Chosen PODs are combined into a global projection matrix \( U \in \mathbb{R}^{n \times r} \) with \( r < n \):.

\[ U = [ \Phi_1, ..., \Phi_r ] \in \mathbb{R}^{n \times r} \]

(3)

- The model, Eqs. (1), is projected to the chosen subspace, using a modified Galerkin projection:

\[ q \approx \tilde{q} = U^T q \]

(4)

- As velocity PODs may not address initial velocity conditions, the residual vector \( R_l \) is introduced in order to ensure initial conditions to be met:

\[ R_l = \tilde{q} - U^T q \]

(5)

Constraint DOF reduction

- A rigid DOF constraint equation is removable if the corresponding Jacobian line \( C_{lj} \) approaches zero when projected by \( U \).

\[ U^T C_{lj} \approx 0 \]

(6)

- A smaller set of constraint equations \( C_l(q) \) ∈ \( \mathbb{R}^l \) with \( l < m \) and athonarecorrelating constraint Jacobian \( C_{lj} \) arise:

\[ U^T C_{lj} = 0 \]

(7)

Engine Model

Flat-plane V8 combustion engine

- Crank drive model in drag mode.
- Consisting of 17 bodies, introducing three translational and four rotational (Euler Parameter) DOFs each.
- A total of 118 constraint equations ensure realistic mounting.
- Frictionless system.
- Applied engine speed curve, Fig. 1, realised by driving torques and a linear torque damper applied to the crankshaft.
- Idle speed = 750 RPM, max. speed = 4500 RPM.

FreeDyn - Scilab Interface

- Use FreeDyn kernel and MBS model on result level and get direct access to MBS system (forces, IOM, Jacobians etc.)
- FreeDyn time integration called by Scilab or use individual solver algorithm coded in Scilab.
- Use of all states, forces and sensitivities for further computations.
- A typical application: FreeDyn as part of an optimization loop controlled by Scilab or straight forward application of reduction algorithms.
- Use FreeDyn GUI as pre- and post-processor.

Results

The engine is driven as shown in Fig. (2) with the first two seconds, the idling cycle, being used to generate velocity snapshots for the proposed POD reduction process at a sampling rate of \( \approx 1 \) kHz. PODs, as shown in Figs. (3 & 4) indicate the reduced order model.

Reduction results

- Five remaining translational DOFs (omitting 46 DOFs or \( \approx 98\% \))
- Seven remaining rotational DOFs (omitting 81 DOFs or \( \approx 93\% \))
- 97 remaining constraint equations (omitting 21 constraint equations or \( \approx 18\% \))
- Error on pos. & vel. level below 5e-06%
- Simulation time reduced by 33%

References


Conclusions

The presented model reduction method is suitable for repetitive simulations, as they are needed for parameter identification, optimal control, optimal input design etc. The model size is significantly lower, which positively impacts the online solver time by, at the same time, ensuring high validity. In the case of considerablyvalid calculations, the found subspace may be checked for validity repetitively every few identification iterations. Otherwise, not only the subspace may change but also omitted constraint equations may act due to changed excitation directions or a change in their point of action. Upcoming work focuses on engine models under random vibrations as well as on defining a reduced adjoint system for further speed-up in optimization and identification tasks.

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FreeDyn is a free simulation software designed for solving challenging scientific and industrial problems in multibody dynamics. It serves as an easy-to-use software tool for modeling mechanical systems including rigid as well as flexible bodies connected by different joints and driven by spline, step or state-dependent forces. FreeDyn can be downloaded at http://www.freedyn.at/download/

Facts:

- Redundant formulation of the rotations based on Euler parameters
- Forward time integration with HHT algorithm (without index reduction)
- Floating frame of reference formulation for bodies
- Geometry imported from a CAD system OR simple geometry designed in the pre-processor
- Beside classical MBS, the research and development team of FreeDyn proposes cooperations in the field of, e.g.: Parameter Identification and Optimal Control Problems of mechatronic systems
- Solutions to very specific problems on multibody dynamics (Customizations to FreeDyn)