September 19, 2012
Anif (Salzburg)

Model Order Reduction for Thermo-Elastic Assembly Group Models

Dr. Jens Saak
representing
Project A06 in SFB-TR/96

Chemnitz UT, Department of Mathematics,
Mathematics in Industry and Technology

Outline

SFB/Transregio 96: Conflicting goals

DFG Transregio SFB 96:
Thermo-energetic design of machine tools

A systemic approach to solve the conflict between power efficiency, accuracy and productivity demonstrated at the example of machining production

SFB/Transregio 96: Conflicting goals

increase **P**roductivity

DFG Transregio SFB 96:
Thermo-energetic design of machine tools

A systemic approach to solve the conflict between power efficiency, accuracy and productivity demonstrated at the example of machining production

SFB/Transregio 96: Conflicting goals

increase **P**roductivity

increase product **Q**uality

DFG Transregio SFB 96:
Thermo-energetic design of machine tools

A systemic approach to solve the conflict between power efficiency, accuracy and productivity demonstrated at the example of machining production

SFB/Transregio 96: Conflicting goals

increase **P**roductivity

increase product **Q**uality

reduce **E**nergy consumption

DFG Transregio SFB 96:
Thermo-energetic design of machine tools

A systemic approach to solve the conflict between power efficiency, accuracy and productivity demonstrated at the example of machining production

SFB/Transregio 96: General approach

Systematic investigation of the possibilities for minimization of thermally driven manufacturing errors

SFB/Transregio 96: General approach

Systematic investigation of the possibilities for minimization of thermally driven manufacturing errors

Compensation

- physical manipulation of the thermoelastic causality chain via machine components
- material/design based
- low energy

Correction

- model or measurement based computation of input corrections
- virtual
- neutral in energy

SFB/Transregio 96:Participating institutions

- **Dresden**
  - **TU Dresden (5 institutes)**
  - **Fraunhofer IWU**
- **Aachen**
  - **RWTH Aachen (4 institutes)**
  - **Fraunhofer IPT**
- **Chemnitz**
  - **Chemnitz UT (5+1 institutes)**
  - **Fraunhofer IWU**

SFB/Transregio 96: Research fields and project groups

A: online/offline machine tool model

submodels – system integration – structure and parameter updates – high fidelity and high resolution simulation

B: parameters and correction

parameter dependence – identification of parameters – development and evaluation of correction algorithms

C: design and evaluation of machines and components

development and evaluation of compensation approaches – new measurement techniques – basis for comparison

SFB/Transregio 96: Research fields and project groups

A: online/offline machine tool model

submodels – system integration – structure and parameter updates – high fidelity and high resolution simulation

A06

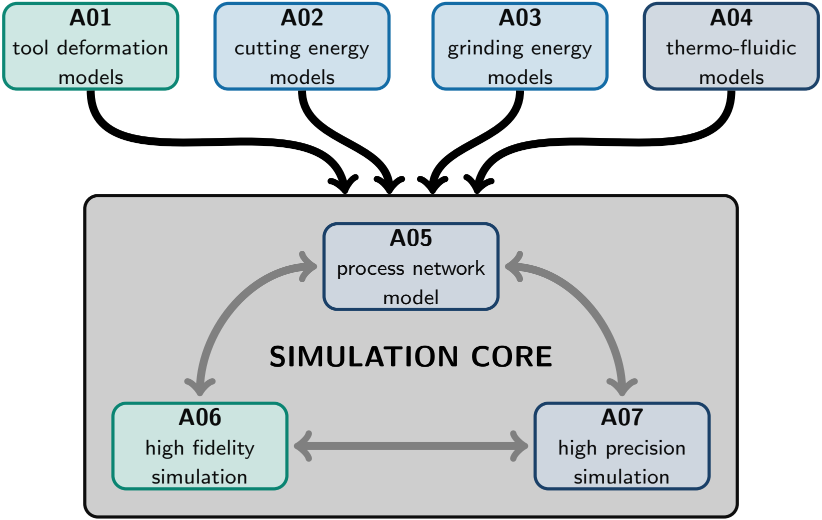
B: parameters and correction

parameter dependence – identification of parameters – development and evaluation of correction algorithms

C: design and evaluation of machines and components

development and evaluation of compensation approaches – new measurement techniques – basis for comparison

SFB/Transregio 96: Online / offline machine tool model



Challenges

- MOR for parametric heat equations
  - Full observation
  - Highly ruffled parameter dependence

- MOR for coupled thermo-elastic models
  - Structure exploitation,
  - Physically interpretable ROMs

- Interplay of MOR, parameter identification and sensitivity analysis

- Time domain system identification
  - Transfer of frequency domain ideas (Loewner approach)
  - Derivation of parametric models

Preliminary Results
MOR for parametric heat equations

Sliding Carriage Support:

- ANSYS FEM model:
  - dofs: $n = 16626$
  - inputs: $m = 1$
  - outputs: $p = n$
- sliding carriage movement
  $\Rightarrow$ input matrix depends on position
- vertical position serves as parameter

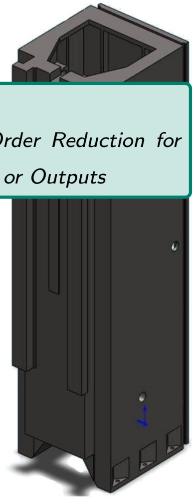
Preliminary Results
MOR for parametric heat equations

Sliding Carriage Support:

- ANSYS FEM model:
  - dofs: $n = 16626$
  - inputs: $m = 1$
  - outputs: $p = n$
    (here: $p = 1 \hat{=}$ temperature mean)

[BENNER/SCHNEIDER '11]
Balanced Truncation Model Order Reduction for LTI Systems with many Inputs or Outputs

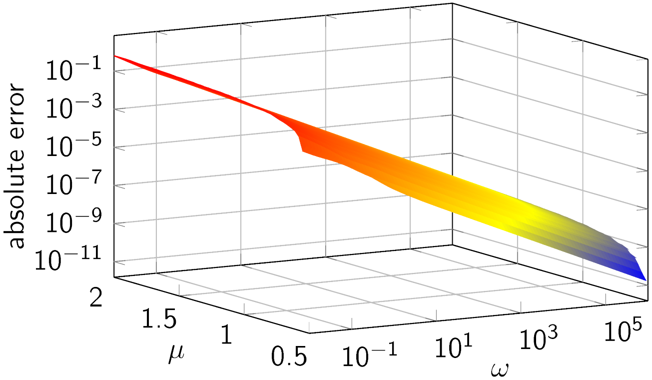
- sliding carriage movement
  $\Rightarrow$ input matrix depends on position
- vertical position serves as parameter
- here: [BAUR/BENNER '09]
  balanced truncation + interpolation



Preliminary Results

MOR for parametric heat equations

Computations by N. Lang
constant parameter mask

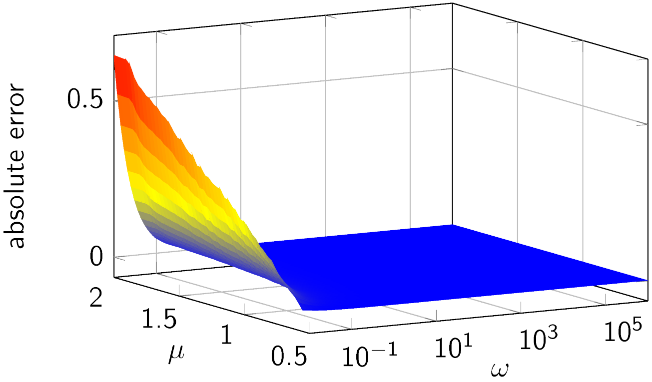


absolute error $\|G(j\omega,\mu) - \hat{G}(j\omega,\mu)\|$ for $k = 5$ interpolation points.

Preliminary Results

MOR for parametric heat equations

Computations by N. Lang
constant parameter mask

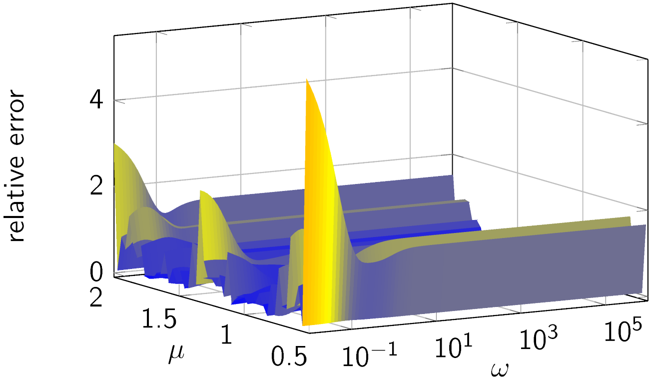


absolute error $\|G(j\omega,\mu) - \hat{G}(j\omega,\mu)\|$ for $k = 5$ interpolation points.

Preliminary Results

MOR for parametric heat equations

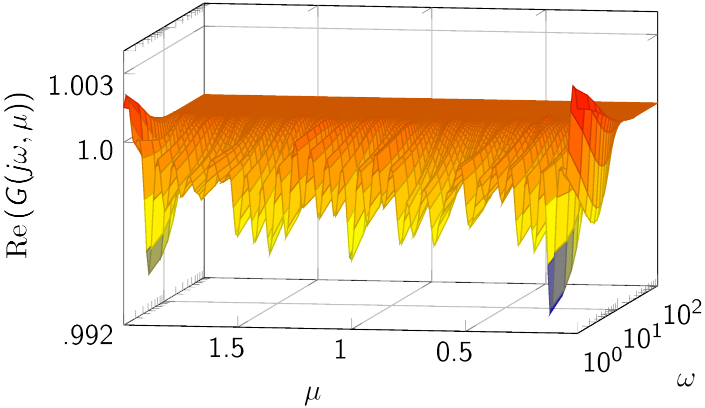
Computations by N. Lang
exponential parameter mask



relative error $\|G(j\omega,\mu) - \hat{G}(j\omega,\mu)\|$ for $k = 5$ interpolation points.

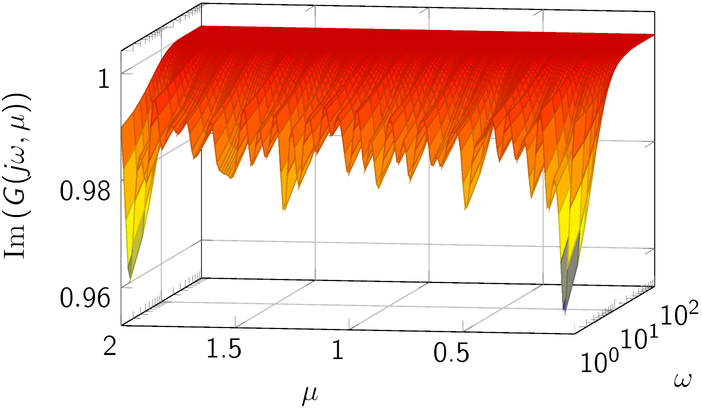
Preliminary Results
MOR for parametric heat equations

Computations by N. Lang
exponential parameter mask



Preliminary Results
MOR for parametric heat equations

Computations by N. Lang
exponential parameter mask



Preliminary Results

MOR for parametric heat equations

balanced truncation + interpolation

- has difficulties with oscillations in parameter direction
- performs better when FEM discretization fine enough on contact surface (for academic test model)
- test with original model still due

Preliminary Results
MOR for parametric heat equations

balanced truncation + interpolation

- has difficulties with oscillations in parameter direction
- performs better when FEM discretization fine enough on contact surface (for academic test model)
- test with original model still due

parametric $\mathcal{H}_2$-MOR

- different strategy for model interpolation
- seems to be more robust w.r.t. oscillations
- PMOR error $\approx$ FEM error for only 5 interpolation point in first tests

Preliminary Results
Time domain system identification

spindle load dependent correction of tool displacements

inputs:

- time domain measurement data for x, y, z, displacements
- 7 rotation speeds of the spindle
- 4 different load values each

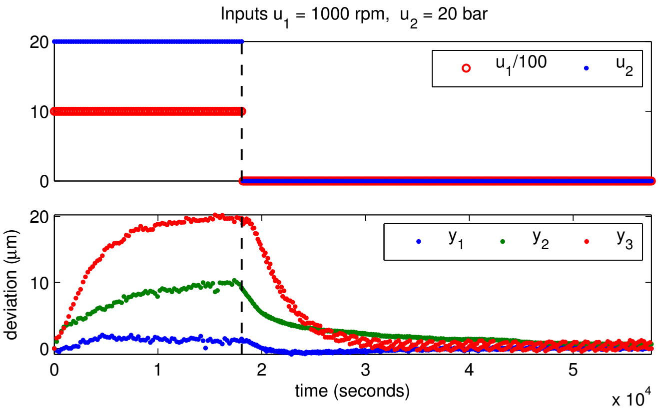
desired output:

- "easy to use" surrogate model for displacement simulations
- preferably "real time" capable
- covering broad range of working conditions

data courtesy of SP B06 (RWTH Aachen)

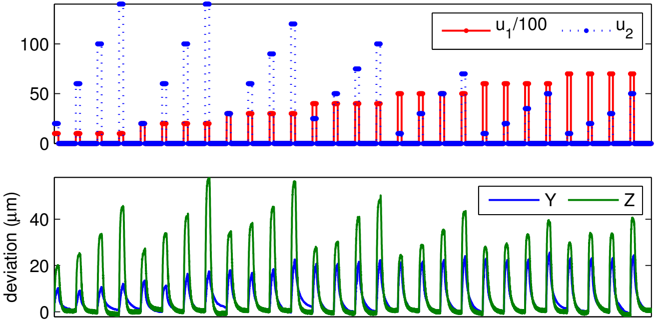
Preliminary Results

Time domain system identification



Preliminary Results

Time domain system identification



Perfect playground for Loewner?

Cooperation with Cosmin Ionita (Rice University)

Unfortunately not!

Cooperation with Cosmin Ionita (Rice University)

- Loewner acts in frequency domain

Cooperation with Cosmin Ionita (Rice University)

- Loewner acts in frequency domain
- transformation of time domain data required
  $\Rightarrow$ FFT/DFT

Cooperation with Cosmin Ionita (Rice University)

Preliminary Results
Time domain system identification

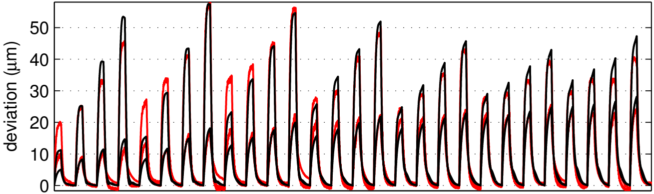
- Loewner acts in frequency domain
- transformation of time domain data required
  $\Rightarrow$ FFT/DFT
- observation:
  adds artificial peaks to the transfer function

Cooperation with Cosmin Ionita (Rice University)

Preliminary Results

Time domain system identification

Fallback: Subspace Identification
(all data sets)

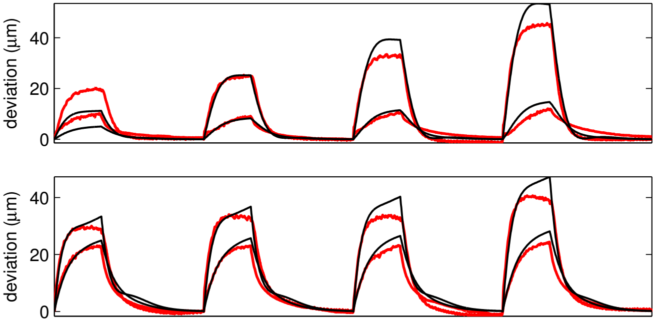


Cooperation with Cosmin Ionita (Rice University)

Preliminary Results

Time domain system identification

Fallback: Subspace Identification
(zoom on first and last sets (1k and 7k rpm))

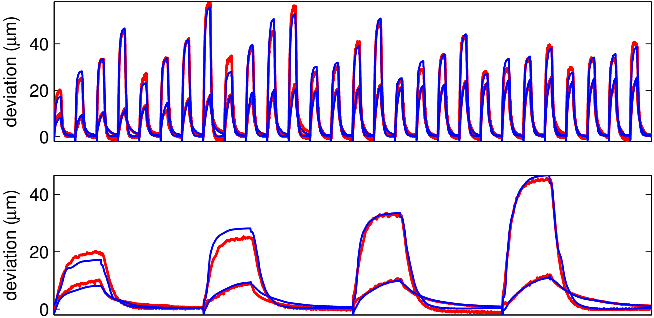


Cooperation with Cosmin Ionita (Rice University)

Preliminary Results

Time domain system identification

Fallback: Subspace Identification
with additional I/O non-linearities)



Cooperation with Cosmin Ionita (Rice University)

Preliminary Results

Time domain system identification

Results

- Methods tried: Fourier+Loewner, partial realization, subspace identification (sid), sid+non-linearity
- sid performed best
- data sets with single rotation speed much better

Cooperation with Cosmin Ionita (Rice University)

Preliminary Results

Time domain system identification

Results

- Methods tried: Fourier+Loewner, partial realization, subspace identification (sid), sid+non-linearity
- sid performed best
- data sets with single rotation speed much better

ToDo: parametric method

- exploit better results for single rotation speed
- use switching or interpolating model

Cooperation with Cosmin Ionita (Rice University)

Questions?

Comments?

Suggestions?