SYSTEM DYNAMICS SIMULATION WITH SIMPACK AND DYMOLA: MILLING MACHINE

3DEXPERIENCE CONFERENCE DARMSTADT, 2019-11-20

VALENTIN KEPPLER, MARTIN HERRMANN,
SVEN REINSTÄDLER, ROBIN BOTH, THORSTEN KROLL

[Cenit logo]

[Synopt logo]
AGENDA

- POC: SIMULATION OF A MILLING MACHINE
- SYSTEM DYNAMICS SIMULATION
  - OVERVIEW
  - TOOLS: SIMPACK & DYMOLOA
  - INTERFACE FMI
- THE MODEL IN DETAIL
- RESULTS
- CONCLUSION AND OUTLOOK
THE MILLING MACHINE
overview, description, data, purpose
Many thanks for the support to 

**Institute of Machining Technology**

TU Dortmund University

**BERGER Group**
MACHINE DYNAMICS SIMULATION?

machine performance:
1. positioning: moving one or more axes of the machine
2. milling: cutting forces acting between cutting tool and workpiece during continuous repositioning

→ focus on the positioning performance (no cutting forces yet!)
   undisturbed positioning

→ follow up: repositioning feed motion during milling process
   disturbed positioning

• motivation: today customers request short positioning times (increase efficiency) → faster positioning
• but: positioning process shall be stable (especially during feed motion)
• risk: instable positioning may damage workpiece (costs!)
MILLING MACHINE

MECHANICS

- machine bed
- actuators, ball-screw-spindles
- linear guides

very low damping in linear guides and ball-screw-spindles!
SYSTEM DYNAMICS SIMULATION

system dynamics, multidomain simulation, tools, standards
multidomain simulation → complex interaction of connected systems

increasing importance of system dynamics simulation as „simple“ mechanical models get superseded by mechatronic systems

Simulation:

• native implementation of all components in one simulation tool
• co-simulation of different sub-models in different simulation packages
TOOLS & INTERFACES WE USED FOR SIMULATION

**Simpack:**
- multibody dynamics
- mechanical parts (machine bed, ball-screw-spindles, linear guides)
- force & torque elements

**Abaqus:**
- modal analysis of machine bed
- generation of input for flexible body input in Simpack

**Dymola:**
- control elements

**FMI:** Functional Mockup Interface
- co-simulation of Simpack (mechanics) and a Dymola FMU (actuator control)
• **Dymola** is a modeling and simulation environment based on the open **Modelica** modeling language.

• **Modelica**: an **object-oriented, declarative, multi-domain modeling language** for **component-oriented** modeling of complex systems ([https://en.wikipedia.org/wiki/Modelica](https://en.wikipedia.org/wiki/Modelica))

Why choosing **Dymola** FMI for co-simulation?

1. good support for FMI in Simpack
2. extendable by inheritance (object oriented)
3. huge number of libraries for different purposes available
Functional Mock-up Interface (FMI) is a tool independent standard to support both model exchange and co-simulation of dynamic models using a combination of xml-files and compiled C-code.
THE MILLING MACHINE MODEL

data conversion, reduction of model details, SIMPACK model, Dymola Model
STARTING WITH CAD-DATA

- (really) many parts (screws and nuts)
- German umlauts

FIRST APPROACH: IMPORT BY CATSIM
DATA FILTERING
after
PREPARATION IN CATIA BEFORE THE EXPORT OF SIMPACK MODEL

- all bodies will be exported connected to the inertial system
- there is no suitable joint marker definition between the bodies reflecting the kinematics
- setting the joint markers will be cumbersome in Simpack

→ do this before export to Simpack:

1. CATIA supports „point in the center of circles“ → set a point where the joint marker shall be located in the Simpack model
2. CATIA can place an axis system on these points → set an axis system in CATIA and a marker will be available on that body in Simpack model
HOW WE MODELED THE BALL-SCREW-SPINDLE

modelled as idealized screw joint
HOW WE MODELED THE LINEAR GUIDES

• in the rigid body model we initially just modeled the effect of these guides by a suitable constraint between machine bed and y-z sled

• as a result of this constraint the state of the screw joint was set to dependent
USE A FLEXIBLE BODY FOR MACHINE BED

PREPARATION OF MODEL IN ABAQUS CAE

- Optimize for meshing
- Prepare nodes for linear guides
- ...
WORK TO DO
generate the markers at the nodes
REFINEMENT OF THE LINEAR GUIDES

- normal forces between fixed markers on the sled and moved markers on the bed
- stick slip elements to apply friction / damping to the system (accounts for normal force)
later the spindle shall be replaced by a beam element and a more realistic elastic coupling between spindle and nut will be implemented
SPINDLE TORQUE CONTROL BY DYMOLA MODEL

position controller

velocity controller

voltage / current controll & motor
TRANSLATE THE DYMOLA MODEL TO A FUNCTIONAL MOCK-UP UNIT
IMPORT THE DYMOLA FMU IN SIMPACK

- use control element 238 to import the generated FMU
- there can exist multiple instances of this FMU (we use the same FMU for both spindle torques)
- the gui parameters are defined in the FMU (in the xml-file) along with their names
- an appropriate communication step size has to be defined!
- no need to run Dymola gui – the FMU dll will be loaded by the solver at begin of integration
- debug output is possible
RESULTS

control parameters, mechanical damping, elasticity, process stability
EXAMPLE FOR STABLE POSITIONING (RIGID MODEL)
EXAMPLE FOR STABLE POSITIONING (FLEXIBLE MODEL)
COMPARE DIFFERENT MILLING PATHS
FAST CIRCLE POSITIONING

Diagram

positioning - trace

Time = 0.020 s
positioning - trace

Diagram

Time = 0.020 s
circle profile:
• low jerk
• good positioning performance

rectangular profile:
• high jerk
• poorer positioning performance

rectangular profile:
• slower speed
• lower mass & inertia for motors
CONCLUSION AND OUTLOOK

project status, weaknesses and missing elements, future model enhancements
already quite good results for this POC:

- a chain of tools of the DS portfolio has been successfully deployed to simulate the system dynamics of machine positioning
- model can be applied to analyze system dynamics (positioning controll) wrt. controll parameters and mechanical parameters

work to do:

- some model parameters have to be determined by supplier data sheet or additional measurement to increase prediction capabilities
- some elements should be modelled in more detail e.g. ball-screw-spindles in Simpack or motor control in Dymola
- missing: good path encoder, jerk filter
- simple „in the loop“ cutting force model should be developed to allow for milling process stability analysis
THANK YOU FOR YOUR INTEREST

VALENTIN KEPLER
Dr. rer. nat. Dipl.-Phys.
+49 711 78 25 – 3508
valentin.keppler@synopt.de

CENIT AG
Industriestrasse 52-54
70565 Stuttgart
www.cenit.com
CITATIONS AND CC-A ATTRIBUTIONS & LINKS
LITERATURE, CC-ATTRIBUTIONS AND LINKS

- **CAD**: Machine model by kind permission of „Institute of Machining Technology TU Dortmund University“ and BERGER Group

- **BSS**: [https://upload.wikimedia.org/wikipedia/commons/7/7f/GearBoxRotLinScrew.gif](https://upload.wikimedia.org/wikipedia/commons/7/7f/GearBoxRotLinScrew.gif) CC-A by: W.Rebel
