Coupled Complete Vehicle Simulation of a Mobile Crane

Dipl.-Ing. Michael Kremb

**Motivation**

**Background**

- Market environment forces manufacturers of agricultural, construction and mobile work machines to use simulation tools for dynamic system description
- Objectives:

  - **Simulation**
    - Reduction of the development costs
    - Reduction of the development time
    - Product improvement

**Problem**

- Vehicle complexity and underlying questions usually make it impossible to represent the complete vehicle in a single simulation environment
  - *non-trivial system of multiple coupled simulation models*
- Relevant system parameters are often not completely known
Motivation

Objectives

- Development, build-up and verification/validation of a model for driving simulation using the example of a mobile crane with a hydropneumatic suspension system
  - Model structure
  - Modeling of subsystems
  - Model verification/validation
  - Model quality, model simplification
  - Use of computing resources
  - Parameter identification
Outline

- Motivation
- Vehicle
- Questions, model requirements
- Suspension system characteristics
- Model structure
- Model verification/validation
- Successive parameter identification
- Results
- Summary and outlook
Vehicle

- 4-axle all terrain crane
- 8 x 8 x 8: all axles steered, driven and equipped with selectable transverse lock
- Electronically controlled rear axle steering
- Hydropneumatic suspension with axle load compensation, hydraulically lockable
- Manual or automatic leveling alternatively
- 4 separated suspension circuits each with 2 hydraulic cylinders and 1 accumulator
- ~ 100 bar static pressure in suspension systems
Questions

- *Driving behavior/safety* (driving maneuvers within the normal range and at the limit, failure analyses, ...)
- *Driving comfort* (rough road tracks, single obstacles, stochastic excitations, ...)

Model requirements

- Possibility of handling and ride comfort analyses
- Detailed model of the mass and inertia properties
- Detailed model of the real suspension kinematics
- Detailed model of the suspension system & the tire characteristic
- Fast, fully parametric and modular model build-up
- Stable and fast calculation (in at most 300 times real-time)
- Simple data analysis (incl. model verification/validation)
Suspension system characteristics

- Realistic representation of suspension system characteristics has decisive influence on the result quality of the simulation.
- Spring effect is mainly based on the nitrogen compressibility.
- Damper effect is mainly based on the hydraulic resistances.
- Hydropneumatic suspension system can’t usually be represented simply in a multi-body environment due to the complexity and the multitude of the relevant influence parameters.
- Method of calculating and computing environment decisively determine simulation time.
**Spring characteristics - pressure calculation**

- Calculation with the aid of thermal equations of state and the energy balance (1. law of TD) in an iterative process
- Virial expansion according to *Bender*
- Heat exchange with the surroundings is considered
  - suitable for all applications

- **V-p-correlation** around OP from complete real gas model
- Heat exchange with the surroundings is not considered
  - only for fast spring compressions/deflections, that is for adiabatic reversible state changes, suitable

- Calculation of the V-p-correlation using the equation of polytropic state changes ( )
  - only for adiabatic reversible state changes suitable
  - good results ranging from 75 to 225 bar
**Damper characteristics - pressure losses calculation**

- Volume flows as a result of the piston motions fully and exactly known
  - analytical calculation for every component possible:
- User-friendly modeling due to a two-stage process
  1. Input, calculation and summarization of the hydraulic resistance parameters in *Excel*
  2. Importing the parameter set (96/24 P.) into *Simpack* in equations of the form:
- Factors taken into account: friction and turbulence losses, type of flow (laminar/turbulent) and direction of flow, pressure- and temperature-dependent oil properties (viscosity, density)

- Very long computing times
- Efficient use is only possible with very specific questions (e.g. local temperature effects of the hydraulic oil)
Model structure
Model verification/validation

- Complex simulation systems imperatively require real measurements for verification/validation
- Measuring assemblies and individual components
- Extensive measurements with a large variety of driving maneuvers on specific test und trial tracks (ca. 80 measuring channels, over 200 measured test runs)
  - Body accelerations
  - Body position
  - Suspension travels
  - Suspension system pressures
  - Break system pressures
  - Steering angles
  - Cornering & steady-state circular runs
  - Lane changes
  - Accelerating
  - Breaking
  - Driving over single obstacles
  - Driving on rough roads
  - ...
Model verification/validation
**Successive parameter identification**

- Identification of yet unknown system parameters with the aid of driving tests and the complete vehicle simulation

![Diagram illustrating the concept of successive parameter identification](image-url)
Results

• Driving over a single obstacle
• Height: \( h=100 \text{ mm} \)
• Speed: \( v=10 \text{ km/h} \)

• Spring deflection of the wheels
**Results**

- Driving over a single obstacle
- Height: $h=100$ mm
- Speed: $v=10$ km/h

- **Pressures in the nitrogen-filled accumulators**
Results

• Driving over a single obstacle
• Height: \( h = 100 \text{ mm} \)
• Speed: \( v = 10 \text{ km/h} \)

• Body accelerations (vehicle center of gravity)
Summary

- Coupled complete vehicle simulation model has been developed
- Suspension system characteristics and tire-road-interactions are calculated driving situation-dependent
- Simulation model has been verified and validated by driving tests
- (Very) good result quality and high computation speed

Outlook

- Study on the parameter optimization (suspension system)
- Study on the system expansion (suspension system)
- Load data generation for service life analyses
Thorough planning
Appropriate structure
Verification/validation

Productive, successful simulation