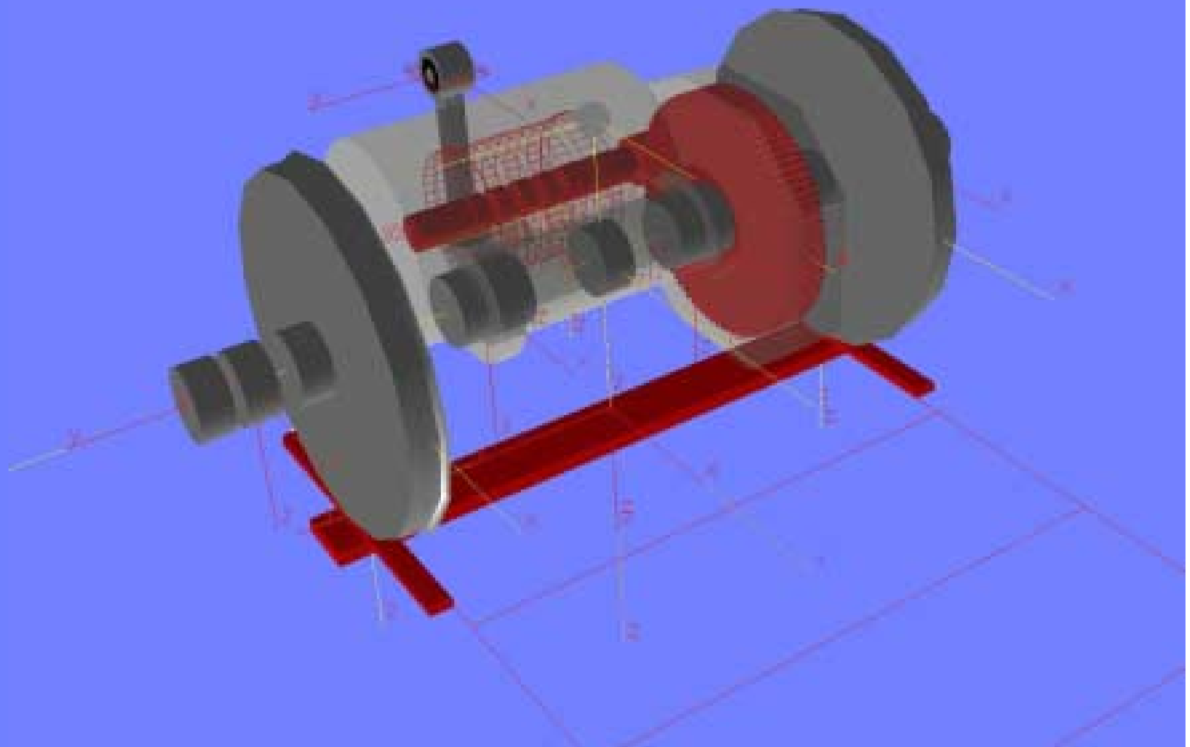
Parameter-Excited Vibrations in Rail Vehicle Drives



Simpack User-Meeting 2007
Bonn-Bad Godesberg, 20.-22.11.07
Erik Pfleger, Siemens AG

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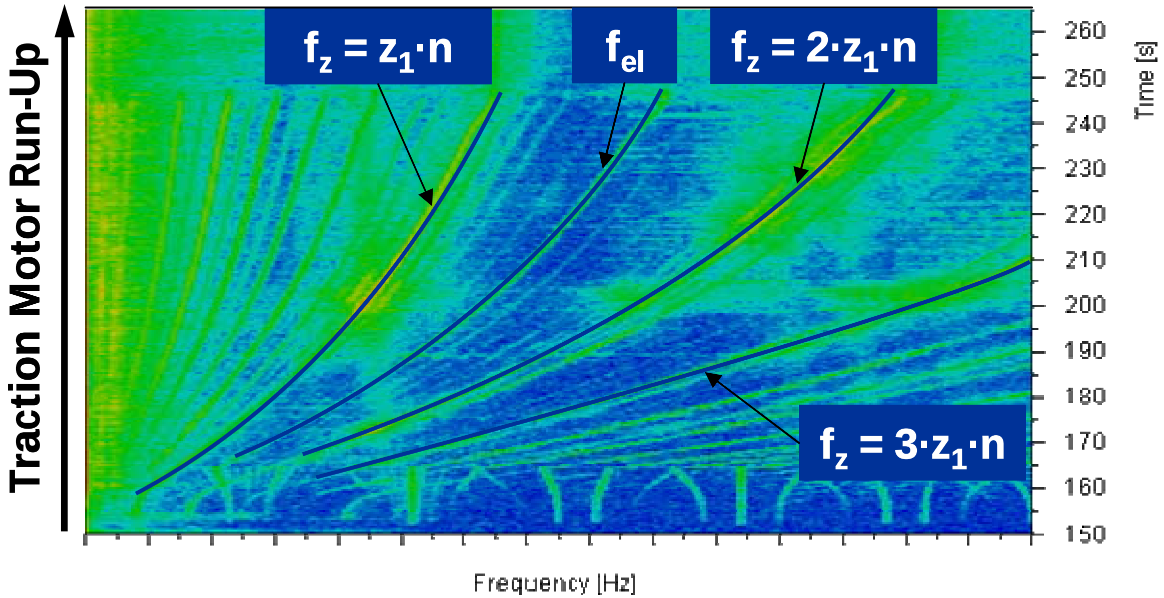
Introduction
Measured Dynamical Behaviour of a Rail Vehicle Drive

Campbell diagram of measured motor shaft torque:



Measured motor shaft torque shows resonances caused by gear excitations predominantly

Dynamical behaviour dominated by gear excitation

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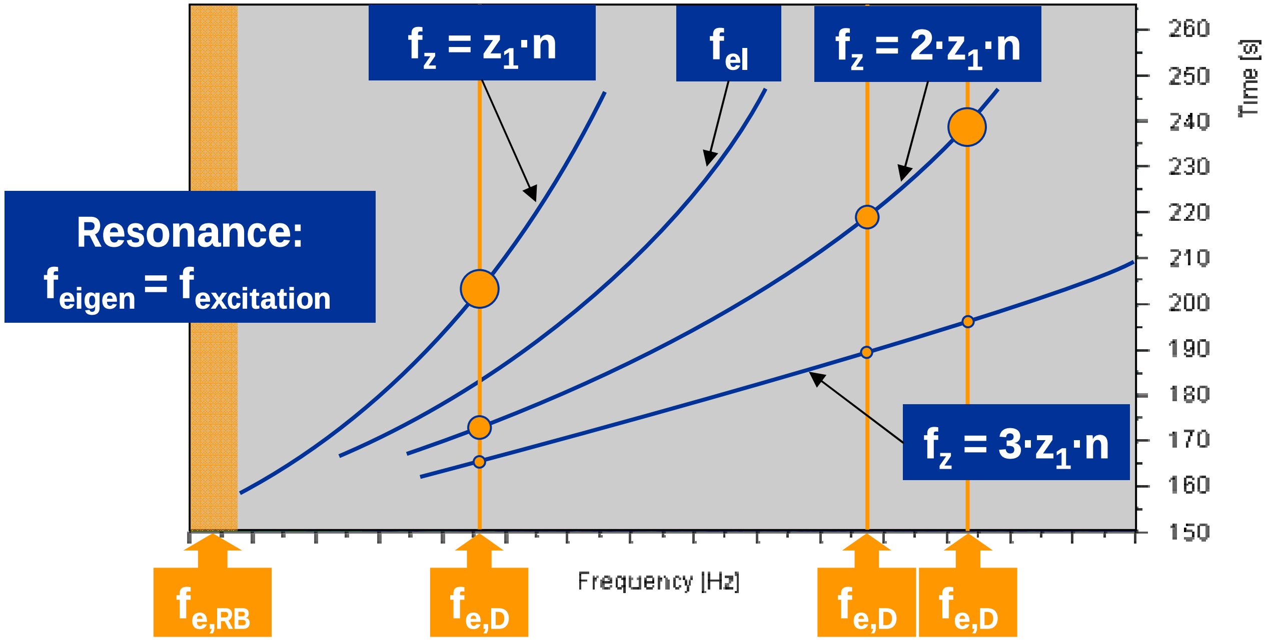
Introduction
Analysis of the Dynamical Behaviour of a Rail Vehicle Drive

Identification of system resonances:



Simulation depends on accurate reproduction of the eigen-frequencies and excitations in the relevant frequency range

Modeling of eigenfrequencies & excitations

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Modeling of the Modal Behaviour
Modal Behaviour of Rail Vehicle Drives

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Modal behaviour characteristics of drives:

- **rigid body motion**
- **torsional vibrations of the drivetrain**
- **bending vibrations of the drivetrain**
- **structural vibrations of drive components**

Example: nose suspended drive for locomotives

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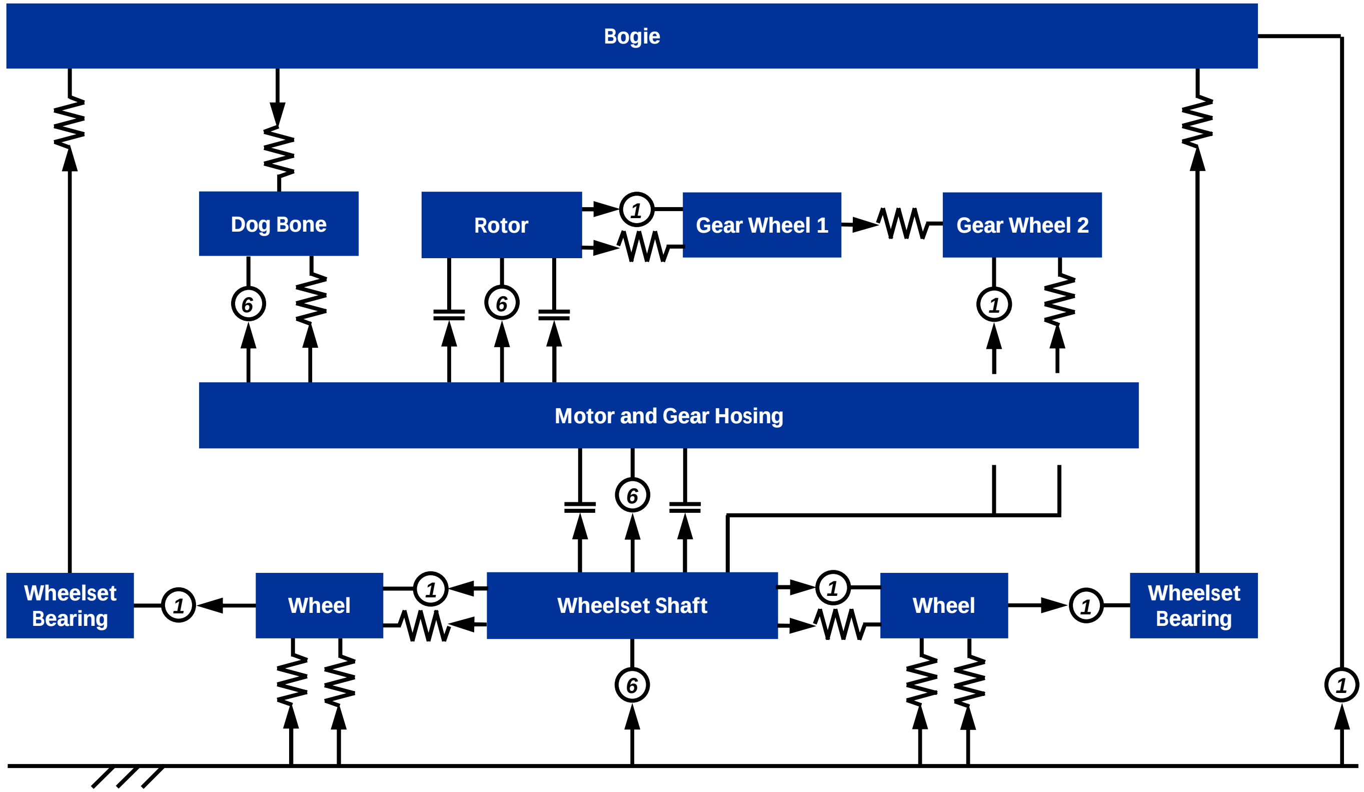
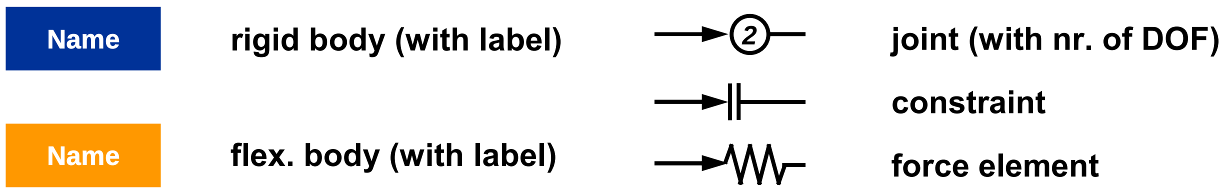
Modeling of the Modal Behaviour
Model Topology with Rigid Bodies for Drivetrain Shafts





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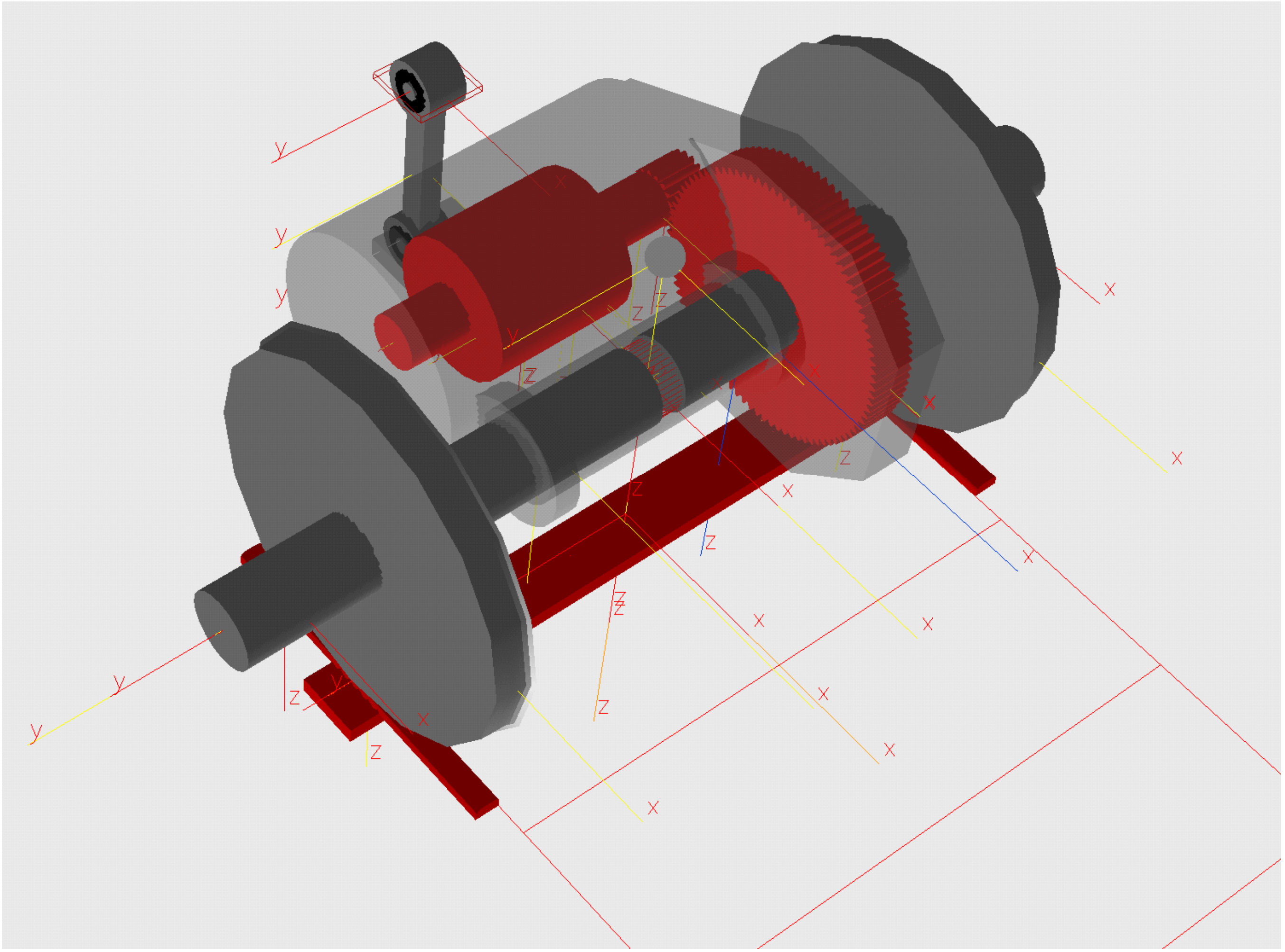
Modeling of the Modal Behaviour
Simulation Model with Rigid Bodies for Drivetrain Shafts



Modeling of the Excitation Mechanism

Typical Excitation Mechanisms for Rail Vehicle Drives

	Description	Cause	Type of Excitation
Traction Motor	pulsating torque	inverter switching	forced excitation
	short circuit-torque	inverter failure	forced excitation
Gear Transmission	tooth mesh	variation of tooth stiffnesses	parameter excitation
	tooth tolerances	damage of tooth flank	forced excitation
Wheel/Rail-Contact	stick/slip	exceed of adhesion maximum	self excitation
	track excitation	rail joints	forced excitation
		track set	forced excitation
		track elasticity	param. excitation
	vehicle oscillations	natural frequencies of vehicle	forced excitation
	wheel out-of-roundness	irregular profile wear	parameter excitation

Modeling of the Excitation Mechanism
Excitation Mechanisms of Gear Transmissions

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Gear excitations caused by:

- **functional gear behaviour**
- **processing of tooth geometry**

Functional Gear Excitations:

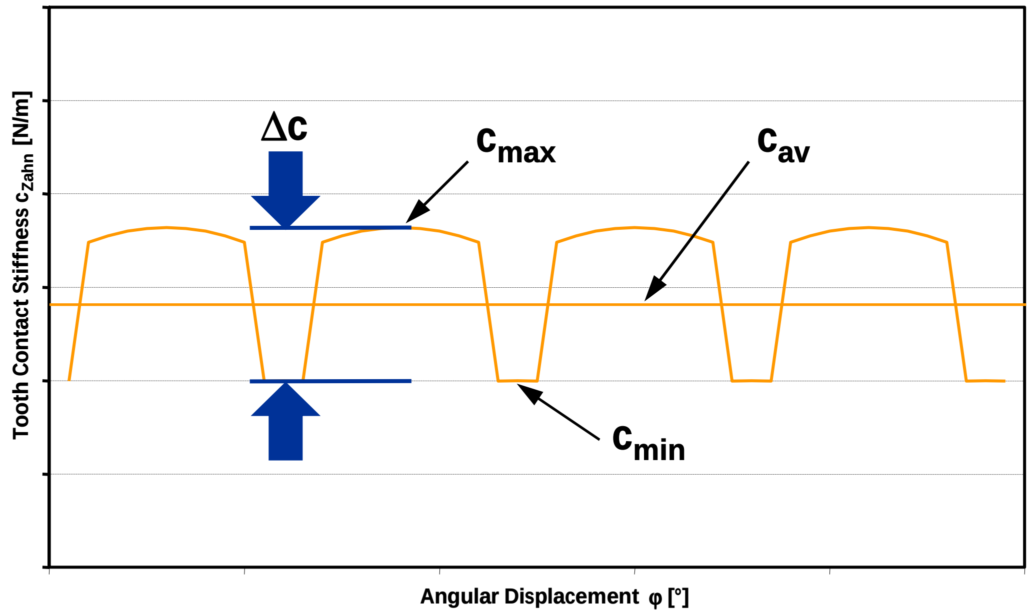
- **meshing impact**
- **negative slip in contact point**
- **transition from single to multiple tooth contact**
- **impulse caused by friction transition in pitch point**
- **positive slip in contact point**
- **discharge impact**

Excitations caused by time-depending parameter

Modeling of the Excitation Mechanism
Parameter Excitation Caused by Gear Mesh

Variable tooth stiffness:

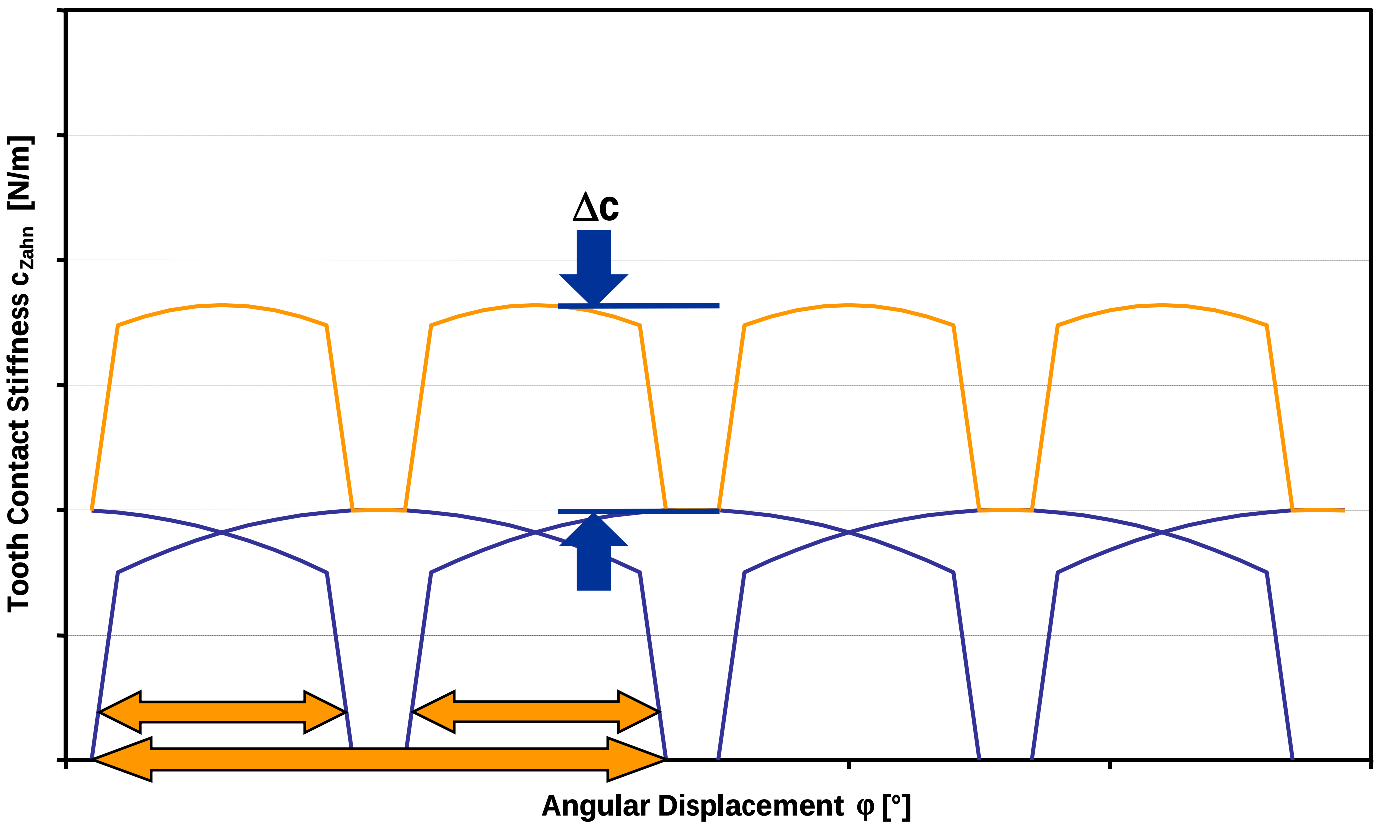
- average tooth stiffness c_{av} → natural frequency of gear
- shape of tooth stiffness → excitation frequencies
- ampl. of tooth stiffness Δc → excitation intensity



Modeling of the Excitation Mechanism

Influences on the Variable Tooth Stiffness

Spur gear with low tooth pair overlap ratio:



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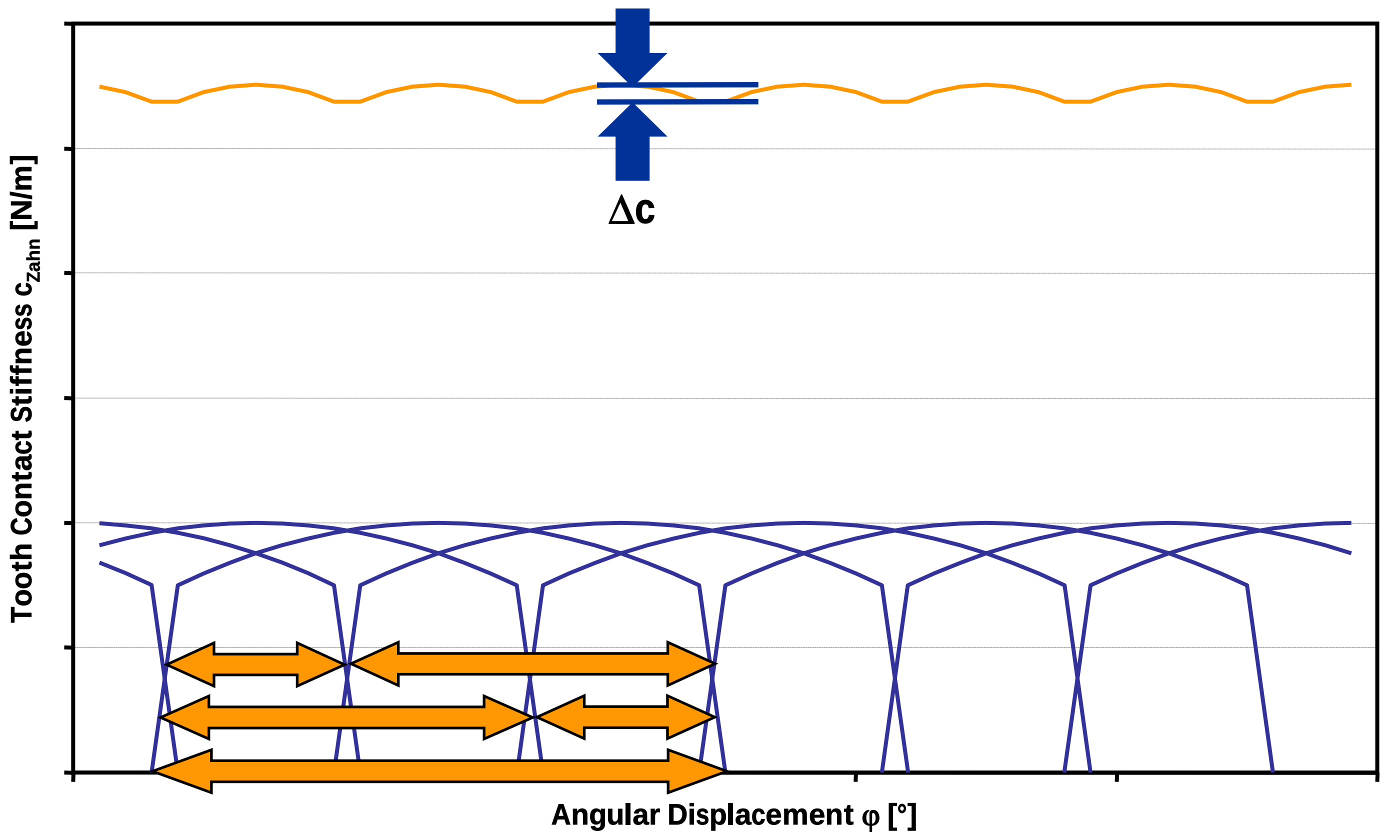
Modeling of the Excitation Mechanism

Influences on the Variable Tooth Stiffness

Spur gear with high tooth pair overlap ratio:



Simulation of the Dynamical Behaviour
Comparison Simulation/Measurement – Time Response

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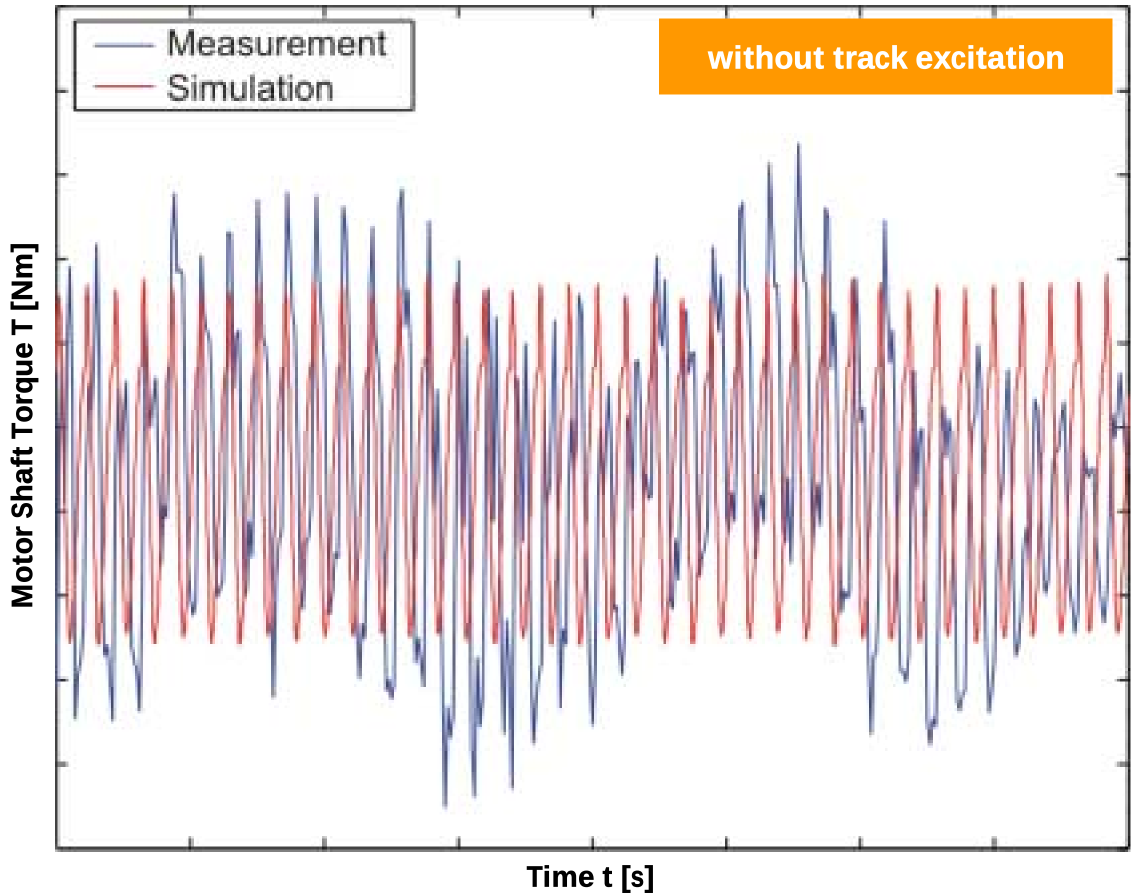
- Introduction
- Modal Behaviour
- Excitations
- **Simulation**
- Modifications
- Results
- Perspectives & Feedback



Modeling of all relevant excitation mechanisms

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Simulation of the Dynamical Behaviour
Comparison Simulation/Measurement – Time Response

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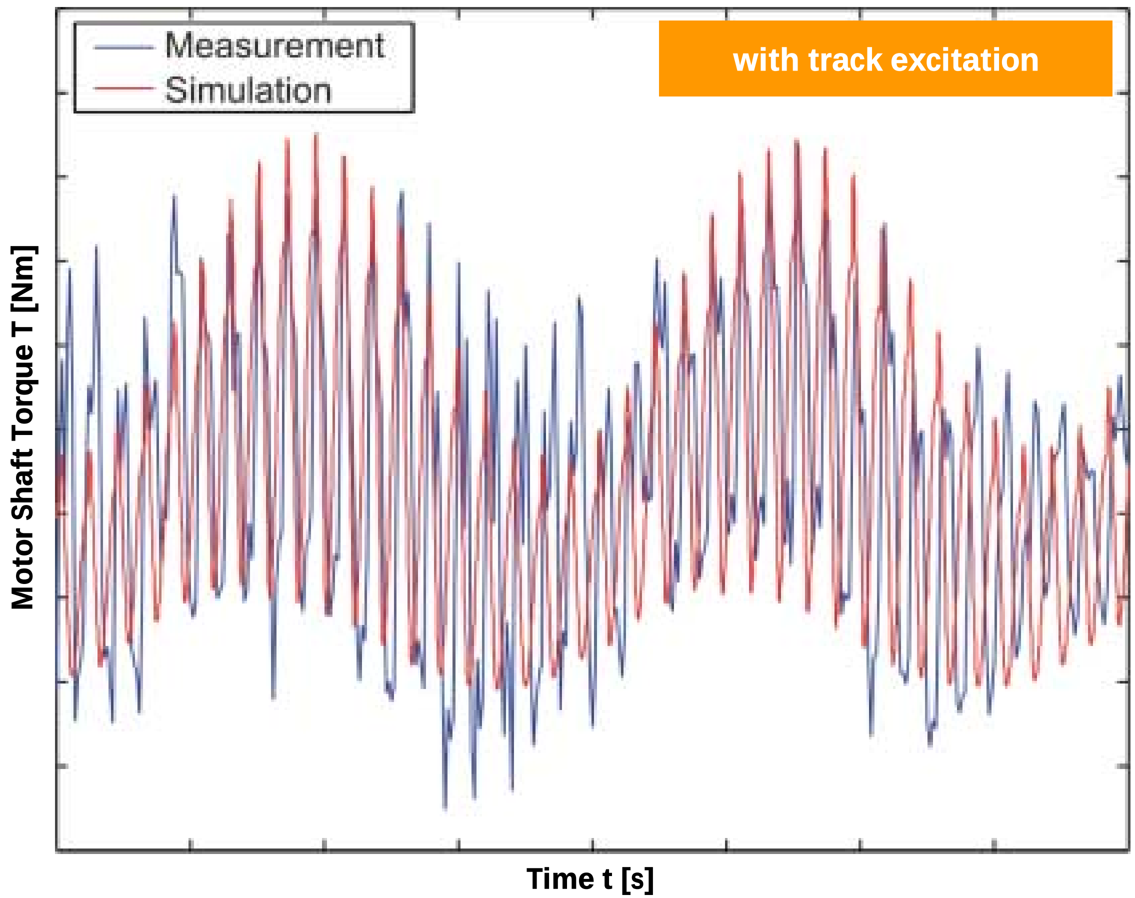

Modifications of the simulation model necessary

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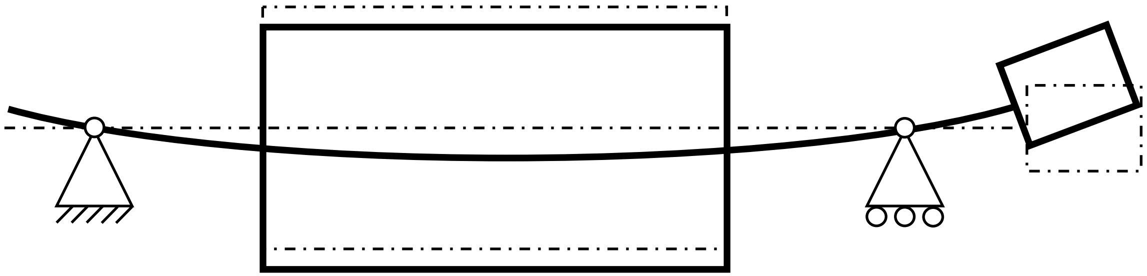
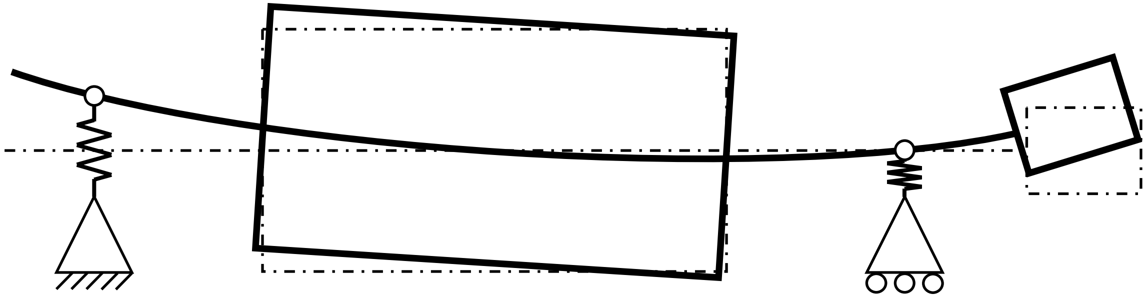
Modifications of the Simulation Model
Consideration of Bending and Bearing Elasticities

Bending of the motor shaft (constrained motor bearings):



Rigid body motion and bending of the motor shaft:



Modifications of the Simulation Model

Model Topology with Flexible Bodies for Drivetrain Shafts

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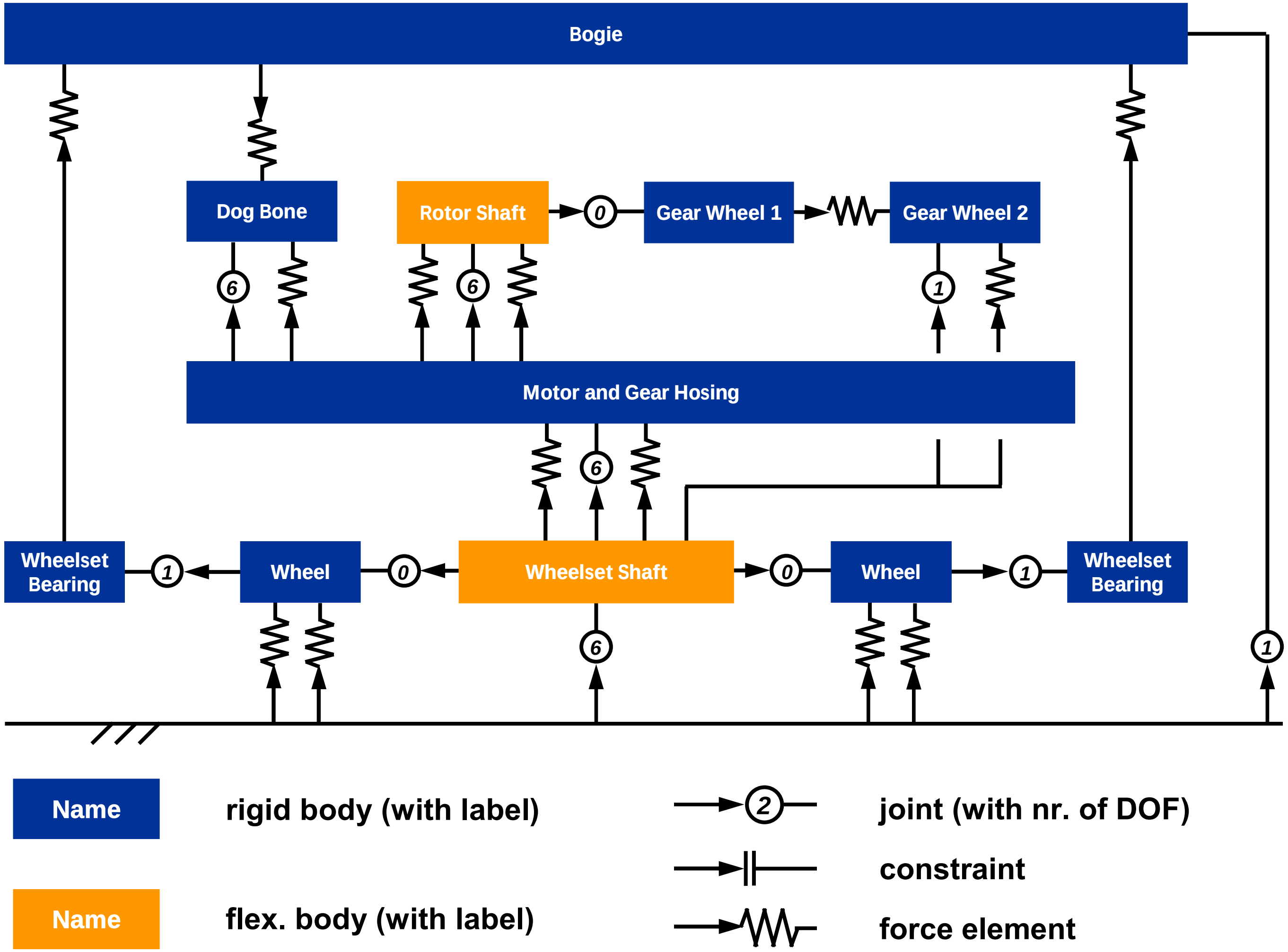

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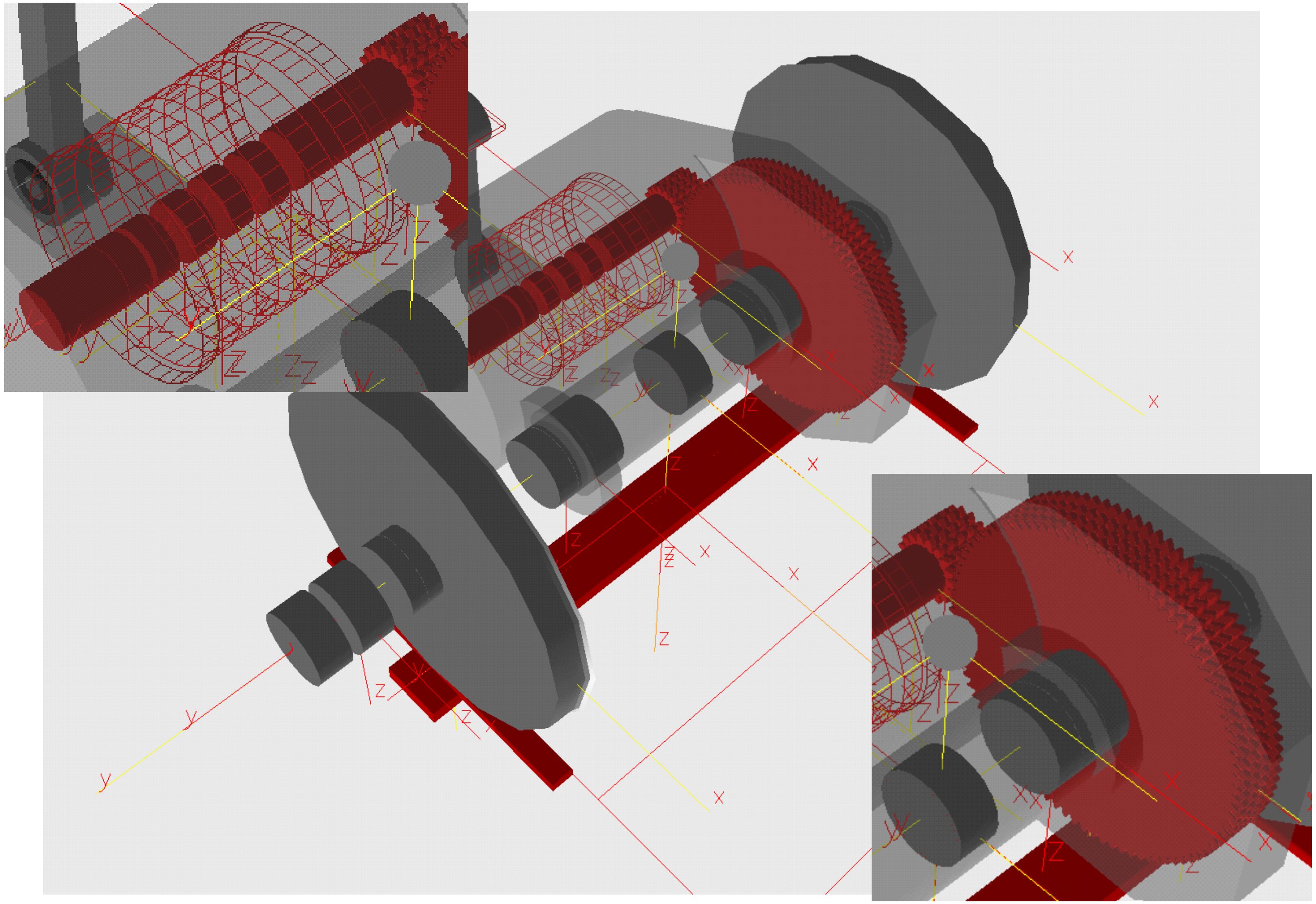
Modifications of the Simulation Model

Simulation Model with Flexible Bodies for Drivetrain Shafts



Modifications of the Simulation Model

Modeling of the Tooth Contact

Relative displacements in tooth flanks:

- **rotational displacement**
- **axial displacement (displ. of pitch point)**
- **angular offset (partial tooth flank contact)**

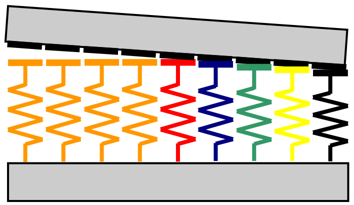
Standard tooth contact modeling:

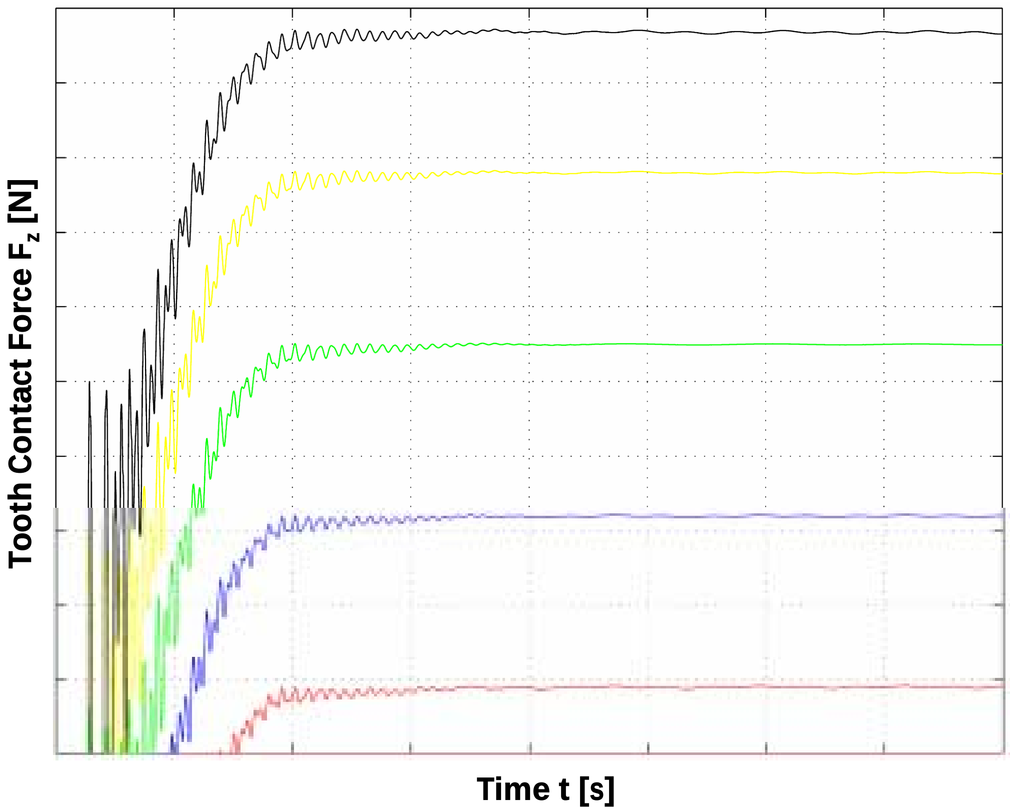
Discretization of the tooth contact:

Modifications of the Simulation Model

Influence of the Tooth Discretization

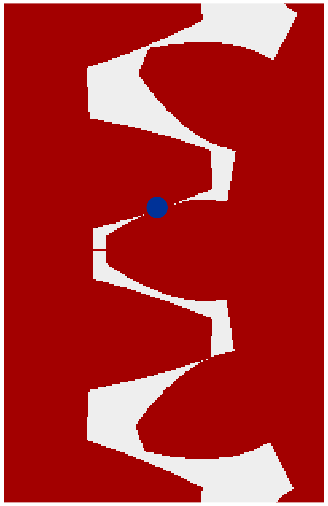
Influence of angular offset on tooth contact forces:

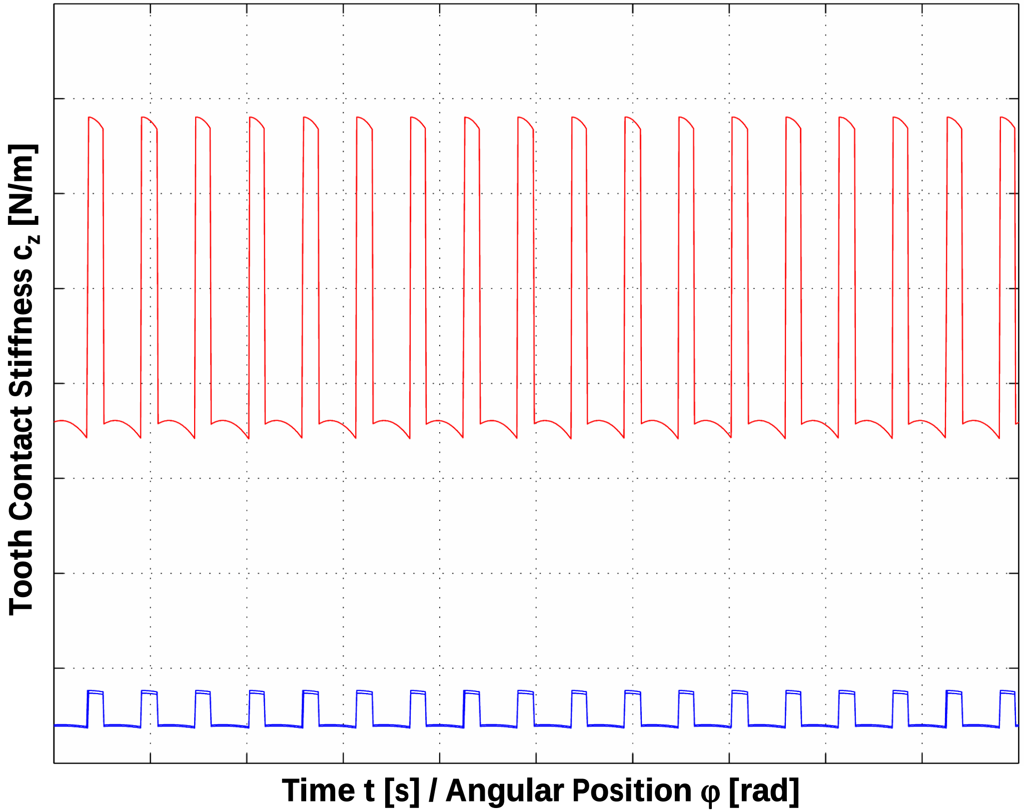




Modifications of the Simulation Model
Calculation of Tooth Stiffnesses for Discretized Gearwheels

Tooth contact stiffness for a spur gear:





Modifications of the Simulation Model

Calculation of Tooth Stiffnesses for Discretized Gearwheels

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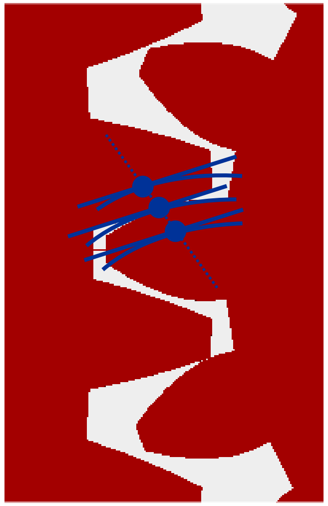
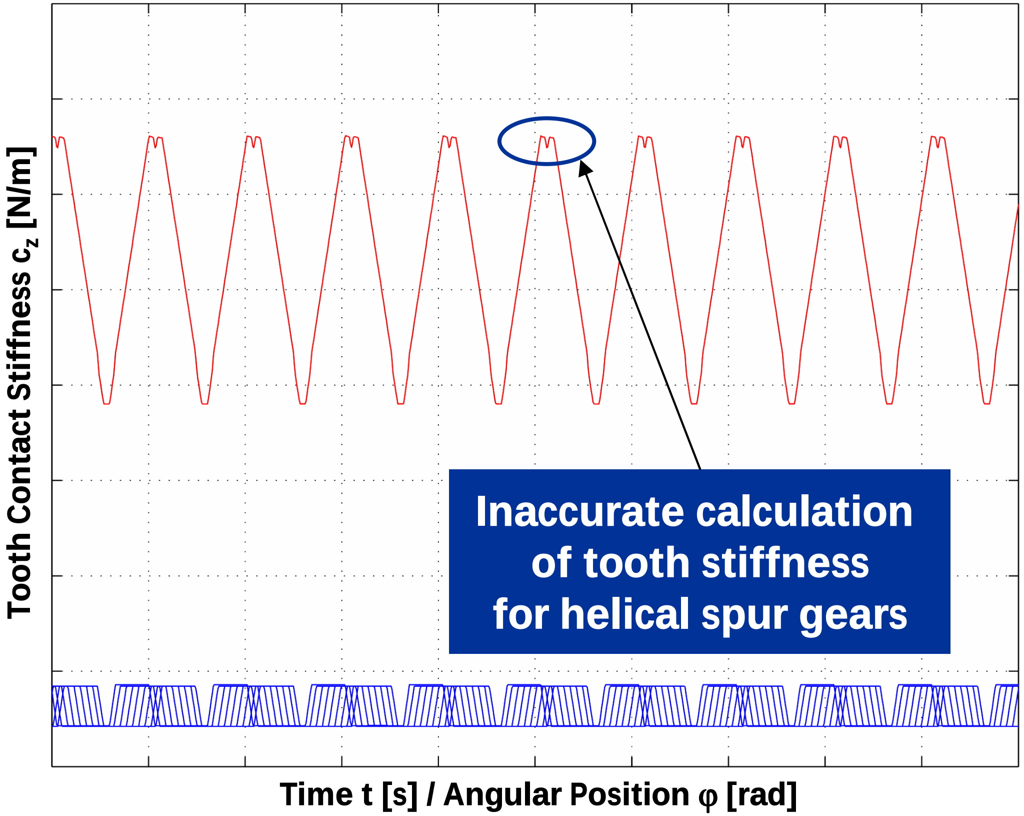
- Introduction
- Modal Behaviour
- Excitations
- Simulation
- **Modifications**
- Results
- Perspectives & Feedback

Tooth contact stiffness for a helical spur gear α_1:





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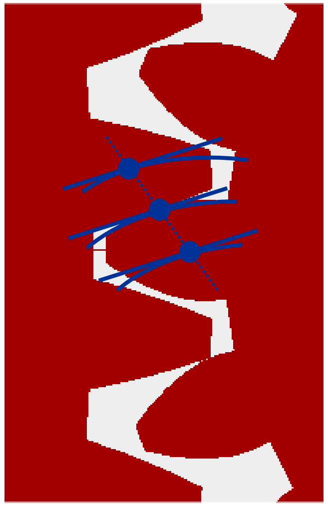
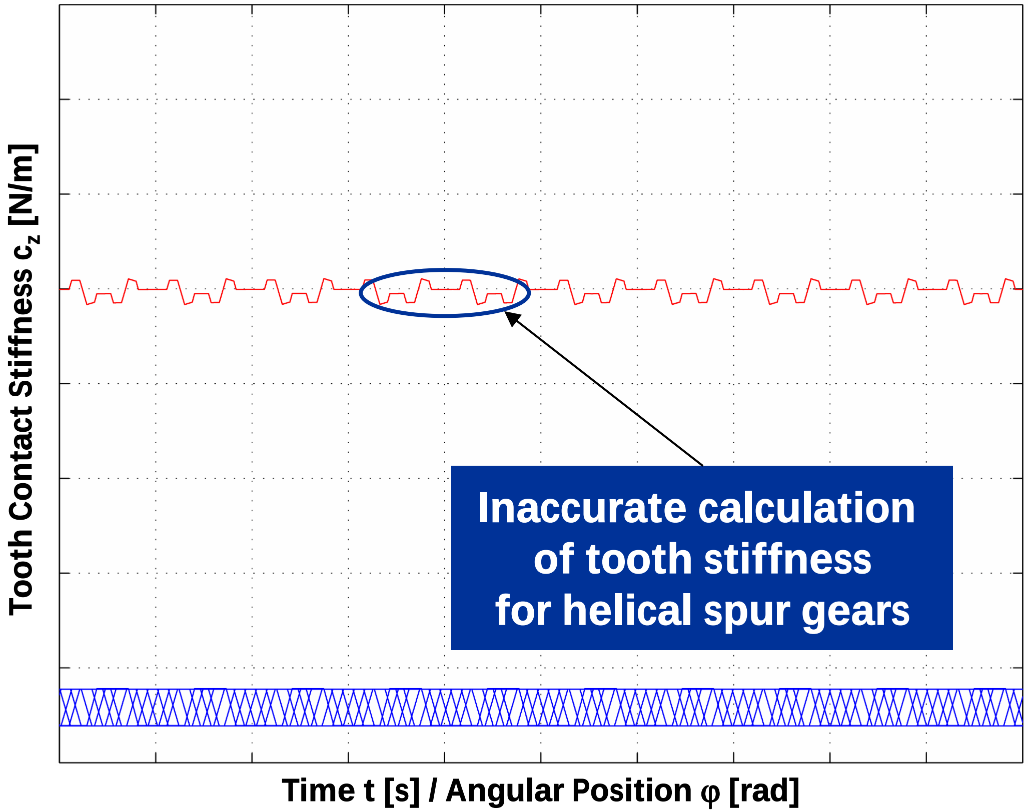
Modifications of the Simulation Model
Calculation of Tooth Stiffnesses for Discretized Gearwheels

Tooth contact stiffness for a helical spur gear α_2:





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Results of the Simulation
Comparison Simulation/Measurement – Frequency Analysis

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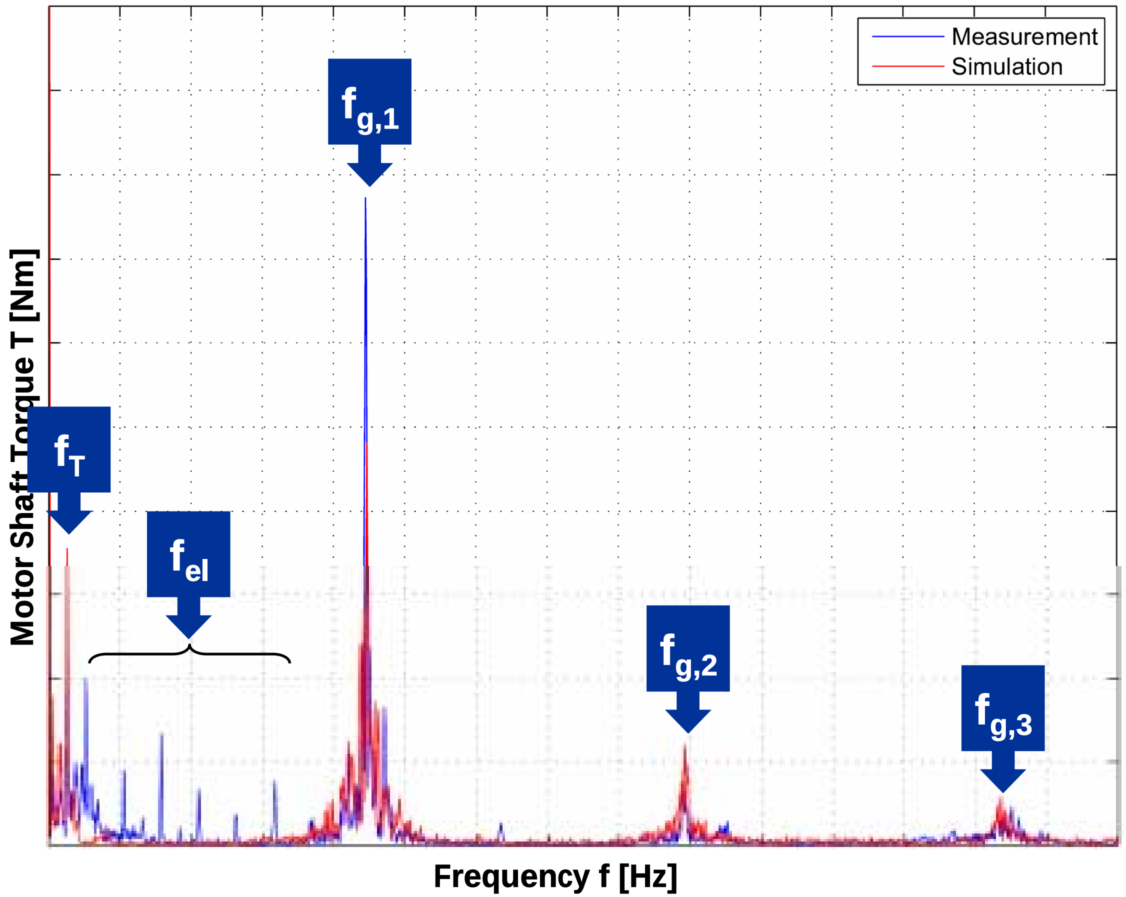
Frequency analysis of motor shaft torque:



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Results of the Simulation
Sideband Excitation caused by Torsional Drivetrain Vibrations

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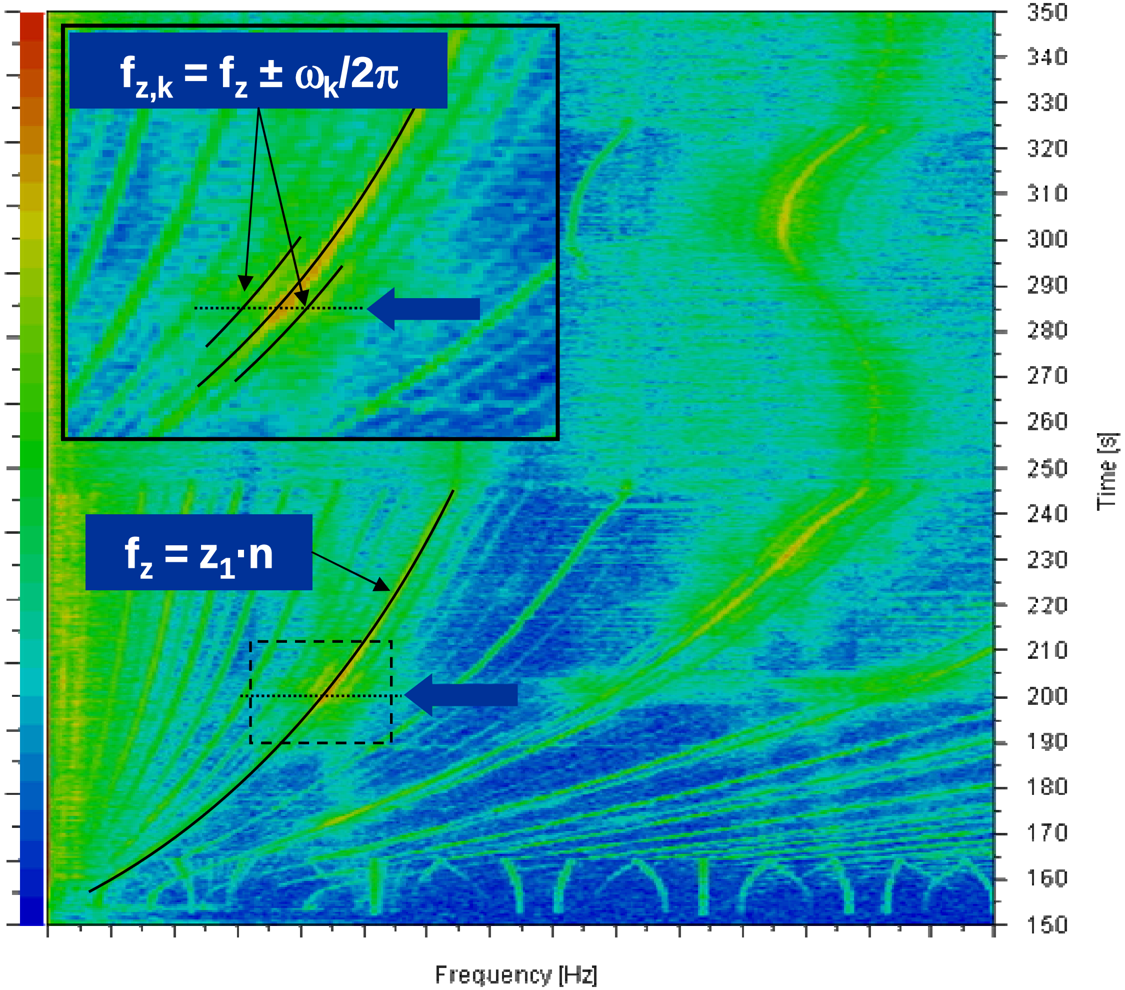
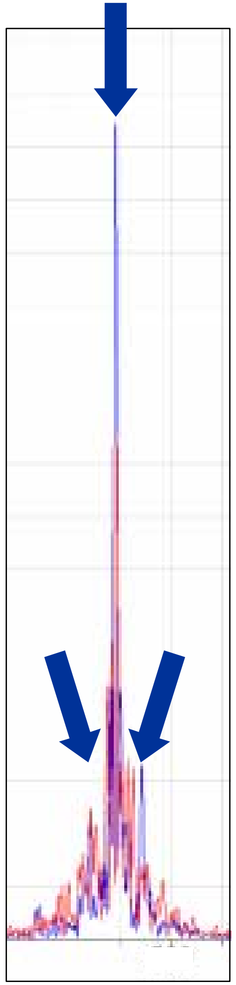
Frequency analysis of motor shaft torque:





Perspectives & Feedback
General Modeling and Simpack-GearWheel

General modeling for rail vehicle drives:

- **Consideration of flexible bodies with torsional <u>and</u> bending DOFs necessary for mid-frequency drivetrain dynamics**
- **Detailed modeling of mechanical traction motor dynamics (squirrel cage rotor) incl. copper cage and lamination stack**

Application of Simpack-GearWheel:

- **Modeling of the parameter-excitation caused by gear mesh sufficient for simulation models with torsional DOFs**
- **More detailed modeling (discretization of tooth contact) for simulation models with displacements of the gearwheels**

Enhancements:

- **Calculation of tooth stiffnesses for discretized helical spur gearwheels (DIN 3990) → Improvement in progress**
- **Modifications of Simpack-GearWheel for calculation of nominal forces, modal behaviour and linear system analysis (Linearization!) necessary**

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