

Design of Active Seat Suspension Mechatronic System

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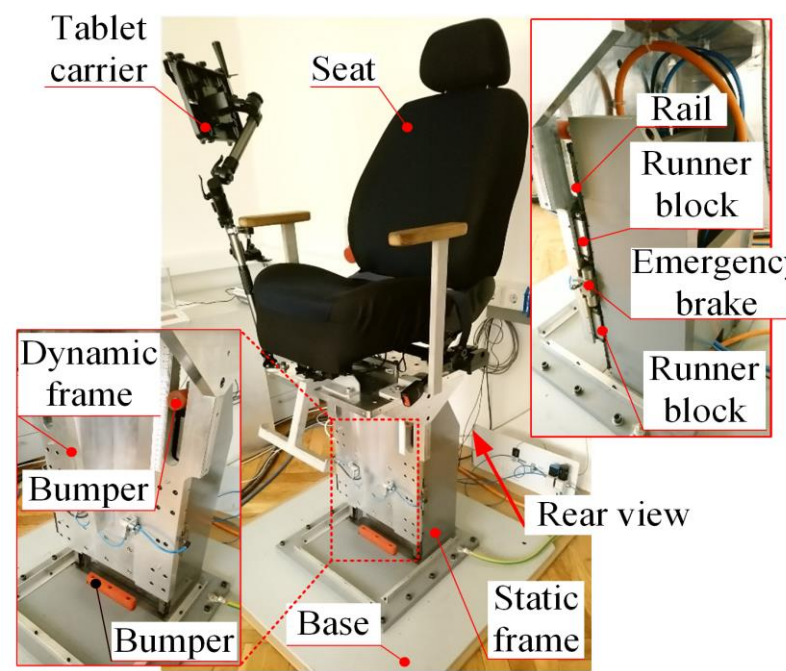
Introduction

The poster first outlines previous research results on LQR-based active suspension control system design and related ride comfort and task execution test outcomes. The results indicate that active seat suspension allows for using stiffer chassis suspension for better handling, while providing a favorable ride comfort. The poster then deals with overall active seat suspension mechatronic system design, including two variants of mechanical subsystem design, actuation system dynamics model, and model predictive control strategy together with low-level controls.

Previous research

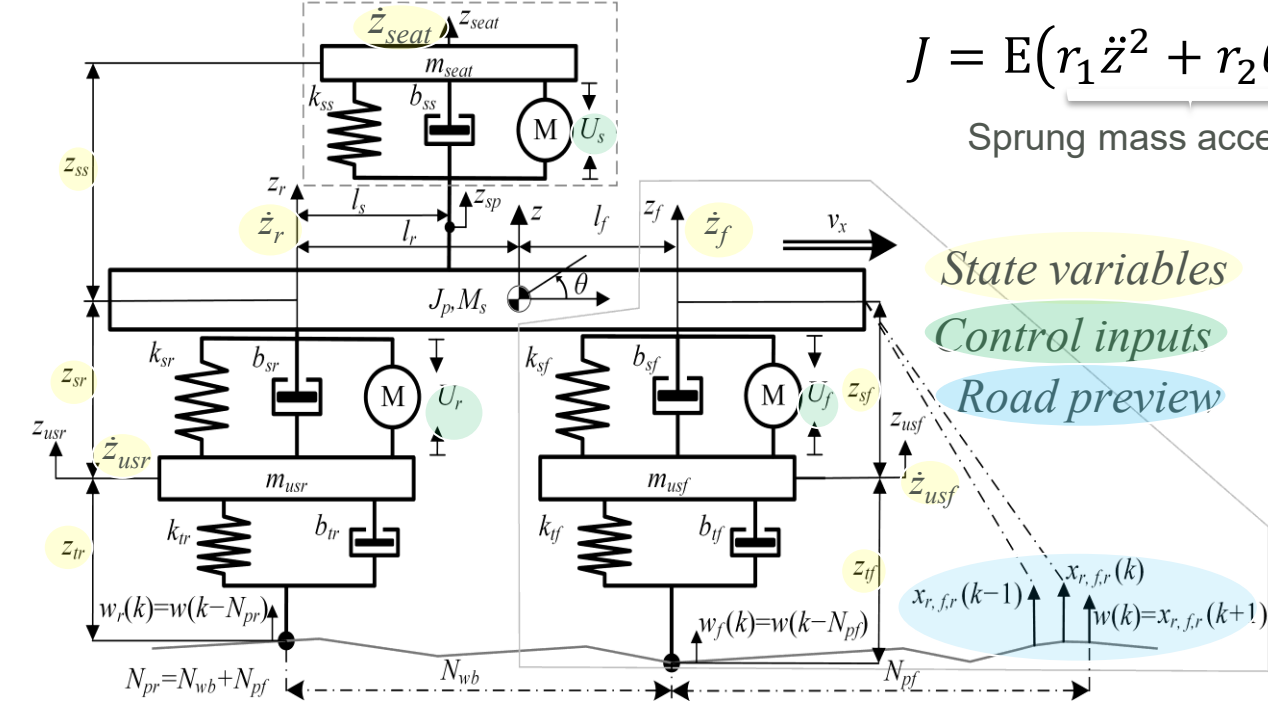
Shaker test rig

- based on the linear servo motor
- 2610 N @ 20 m/s, 6900 N @ 0.6 m/s maximum force @ speed
- 2.5 g @ 0.6 m/s, 1.8 g @ 1 m/s max. vertical net acceleration
- ±1 m/s max. vertical velocity
- ±100 mm max. vertical displacement



FAS - fully active; FASP - fully active w/ preview; SAS - semiactive; SASP - semi-active w/ preview

Half-car model



LQR cost function

$$J = E(r_1 \dot{z}^2 + r_2 \ddot{\theta}^2 + r_{3f} z_{tf}^2 + r_{3r} z_{tr}^2 + r_{4f} z_{sf}^2 + r_{4r} z_{sr}^2)$$

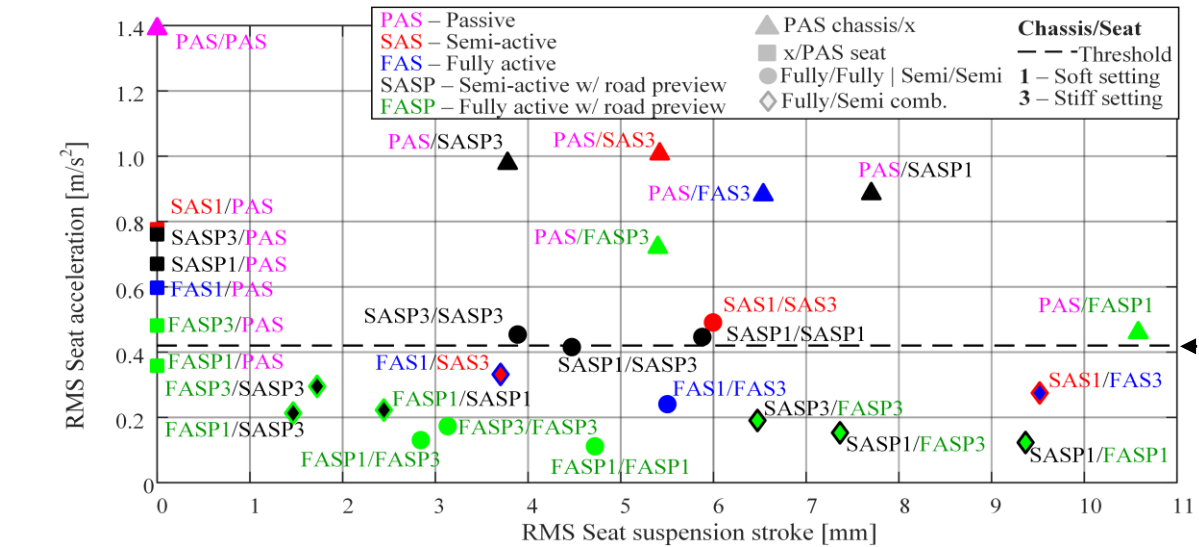
Sprung mass acceleration Tire deflection Suspension deflection

State variables

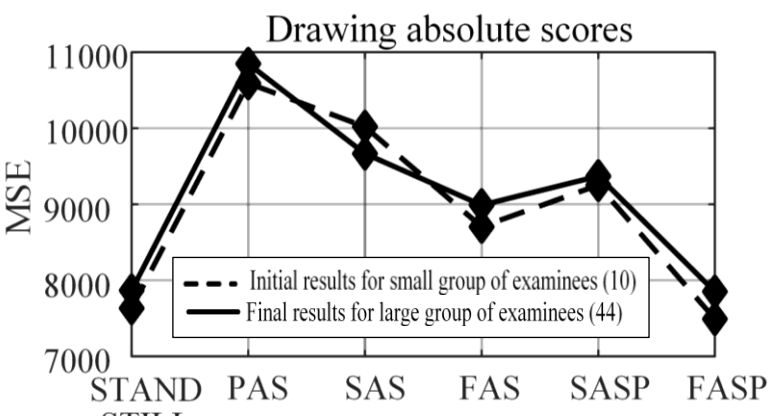
Control inputs

Road preview

Comfort versus seat stroke performance plot

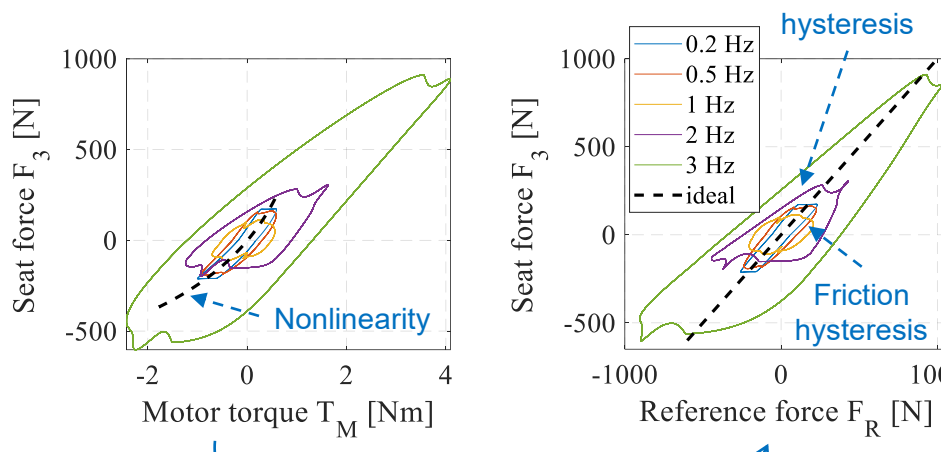


Drawing task evaluation results



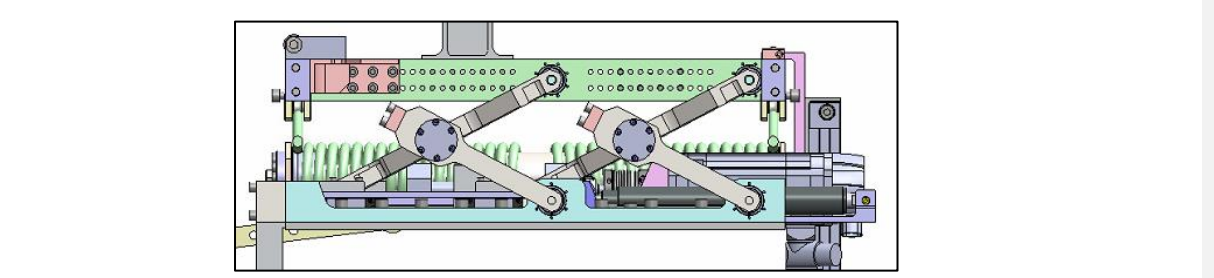
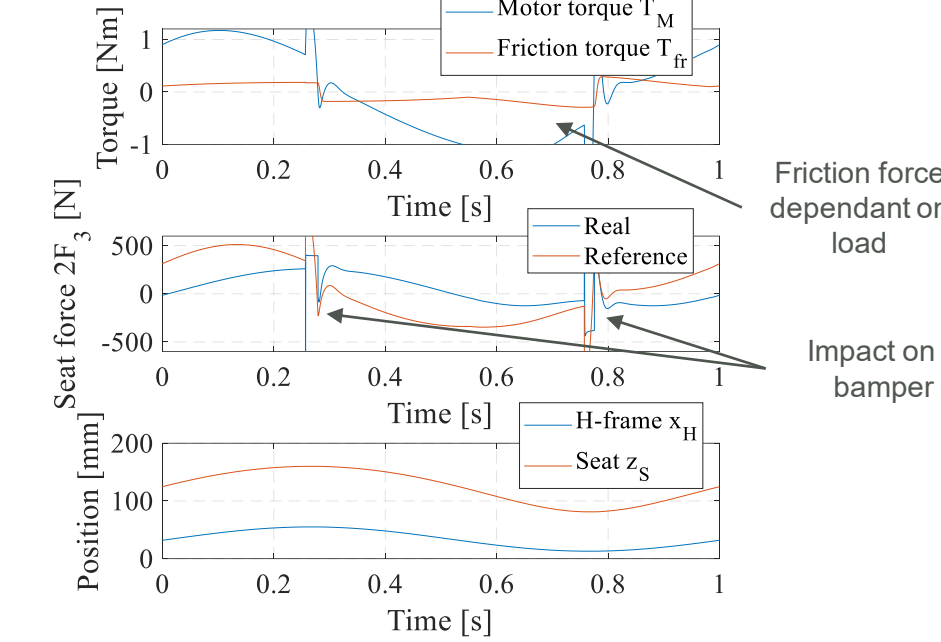
Modelling

- Mathematical model for Design 1
- Inertia: Motor/spindle, H-frame, Seat, Driver
- Friction: Spindle, Seals, Guides, Bearings
- Nonlinear mechanism kinematics
- Bumpers, Torsional springs

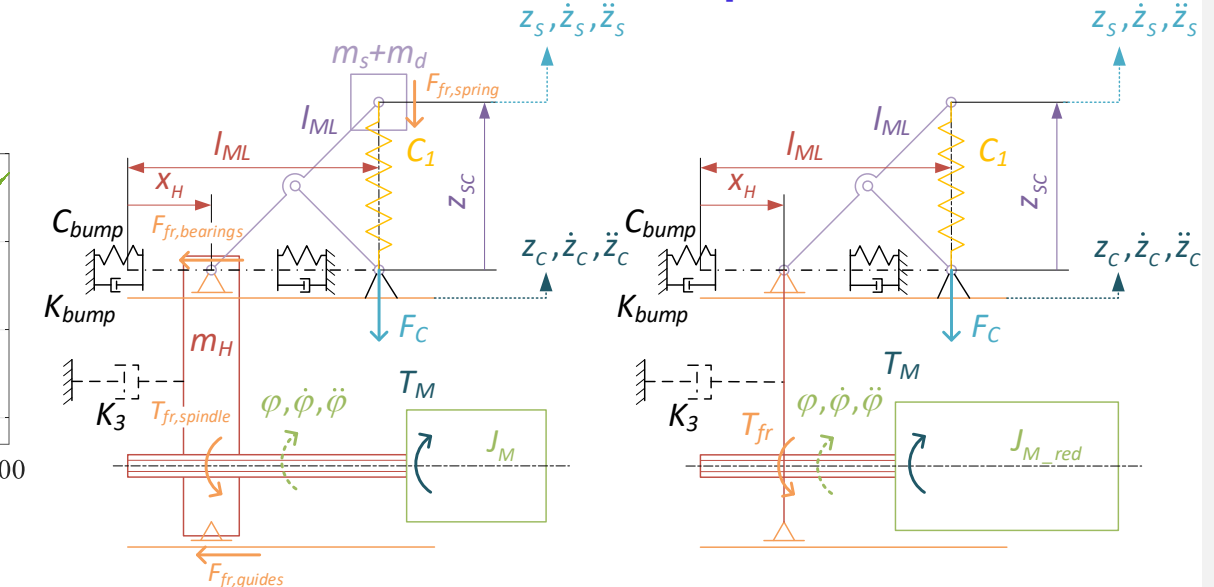


Linearization: $F_R = T_M \frac{2\pi \sqrt{2x_H l_{ML} - x_H^2}}{Ph} \frac{1}{l_{ML} - x_H}$

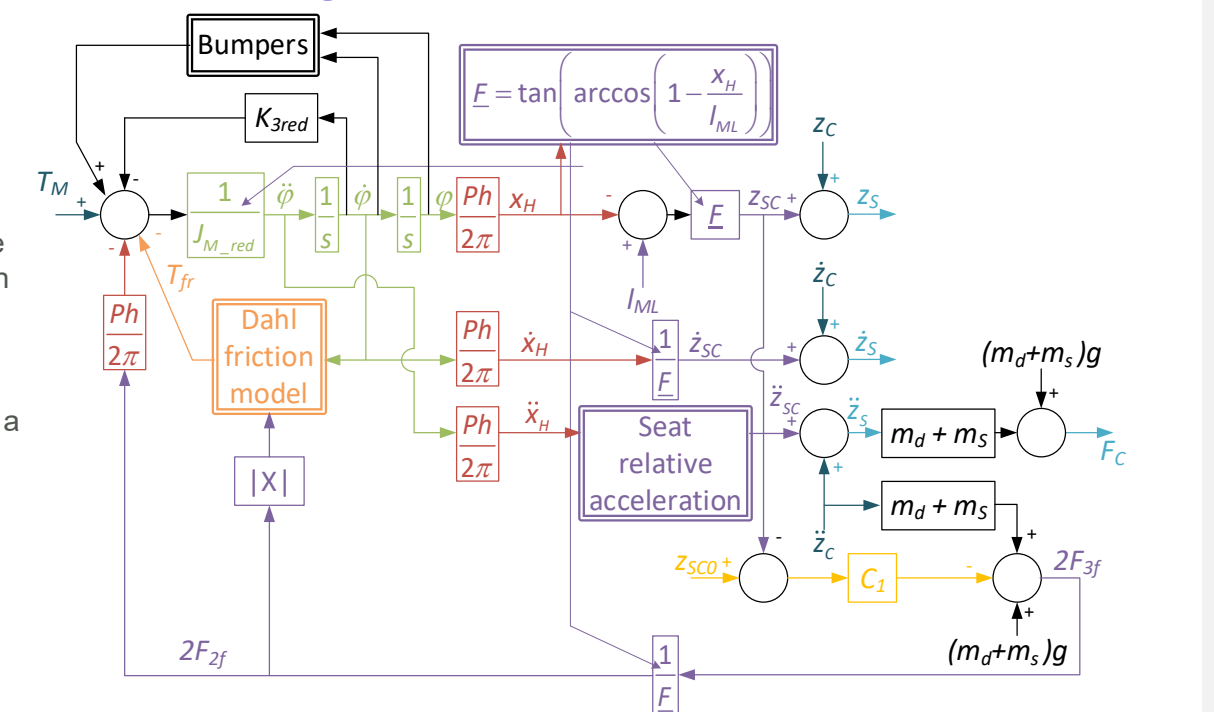
Time response for sine change of feedback controlled seat position reference



Full mechanical model

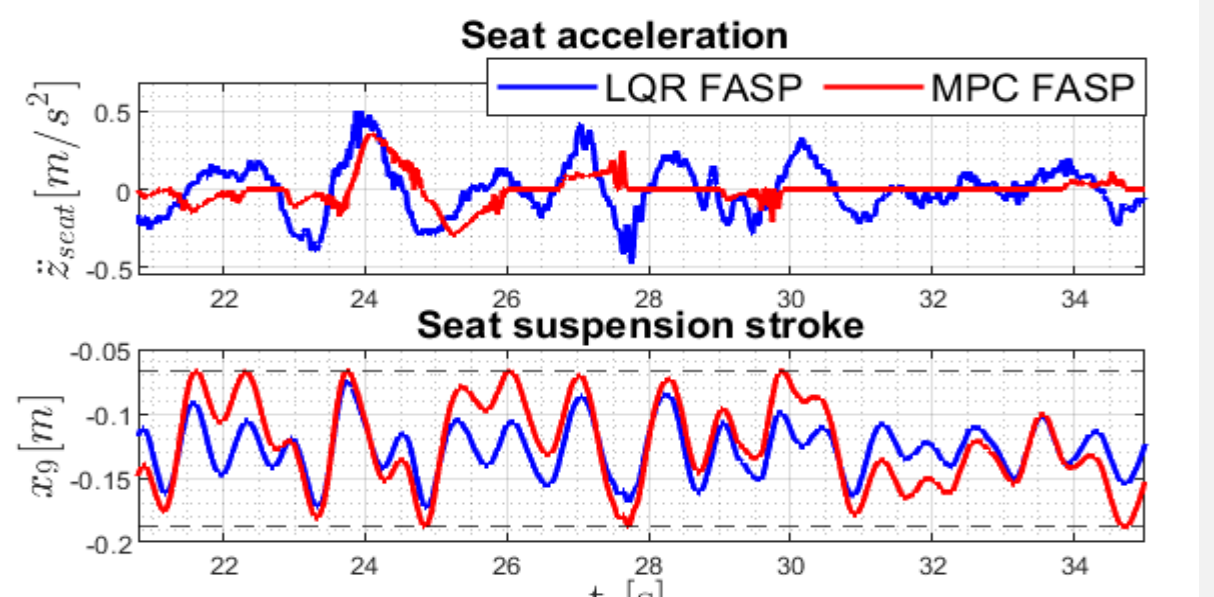
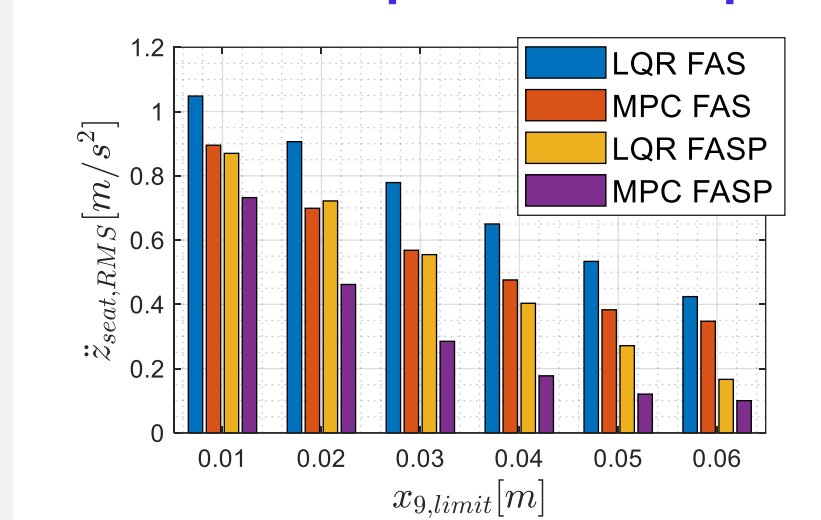


Block diagram

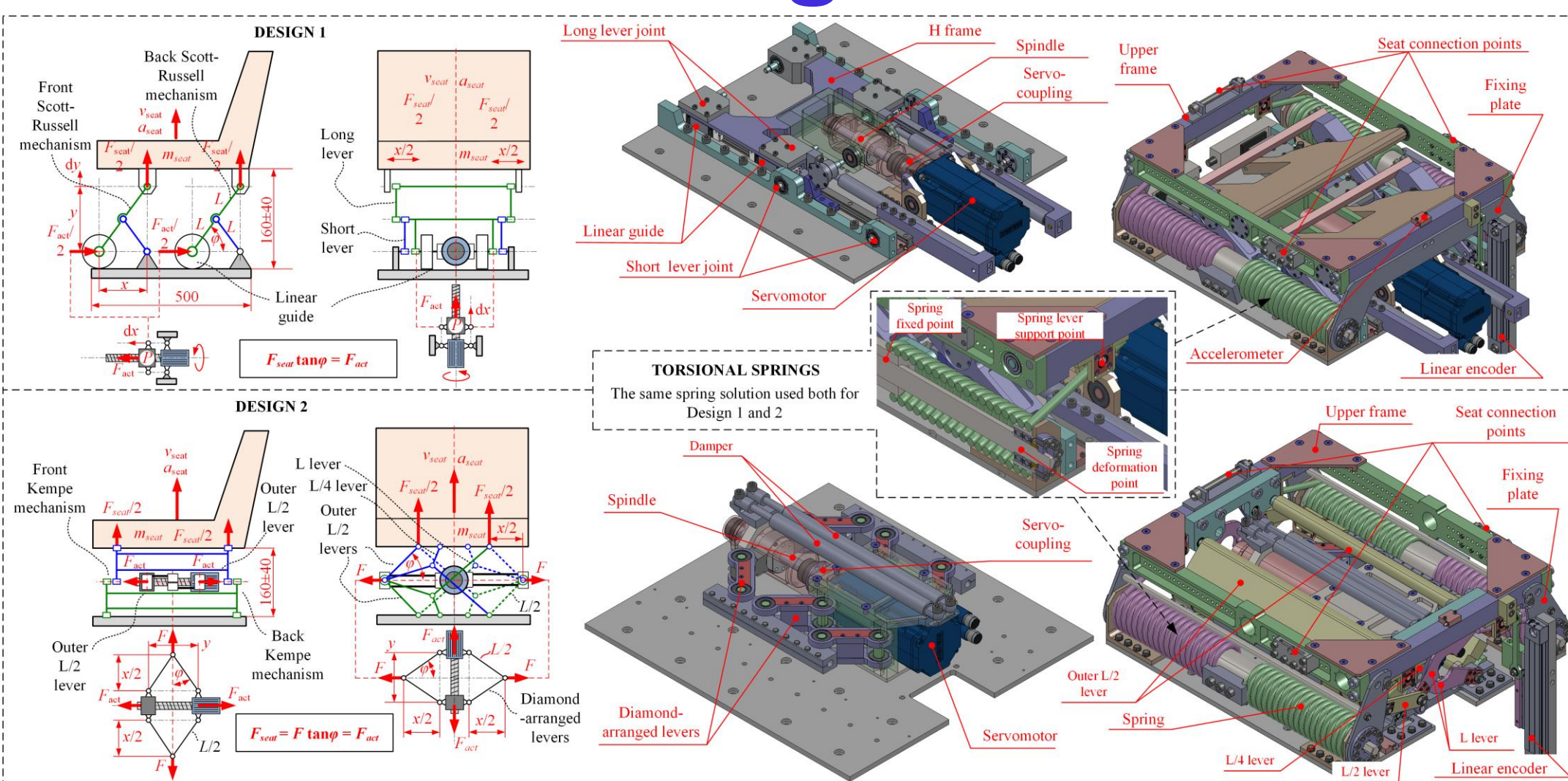


Control

LQR vs. MPC performance plot



Mechanical Design

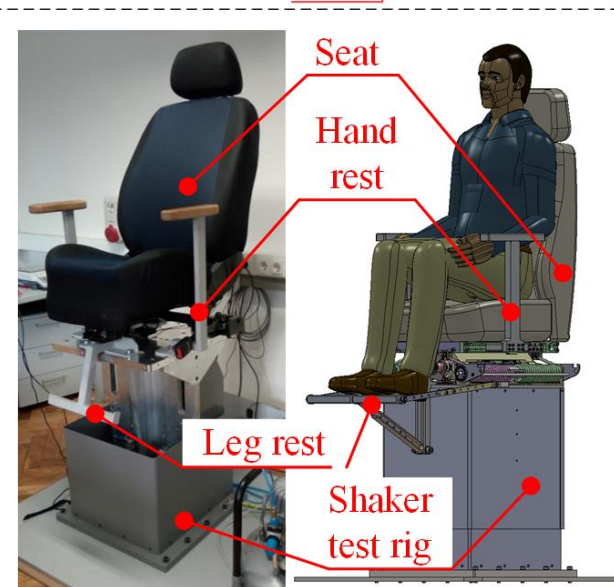


DESIGN 1 - Dual Scott-Russell mechanism

- Best mechanical properties
- High costs
- Suitable for experimental purposes

DESIGN 2 - Kempe mechanism + diamond-arranged levers

- Low cost (no linear guides, smaller motor due to constant transfer ratio)
- Lower stiffness
- Good candidate for mass production

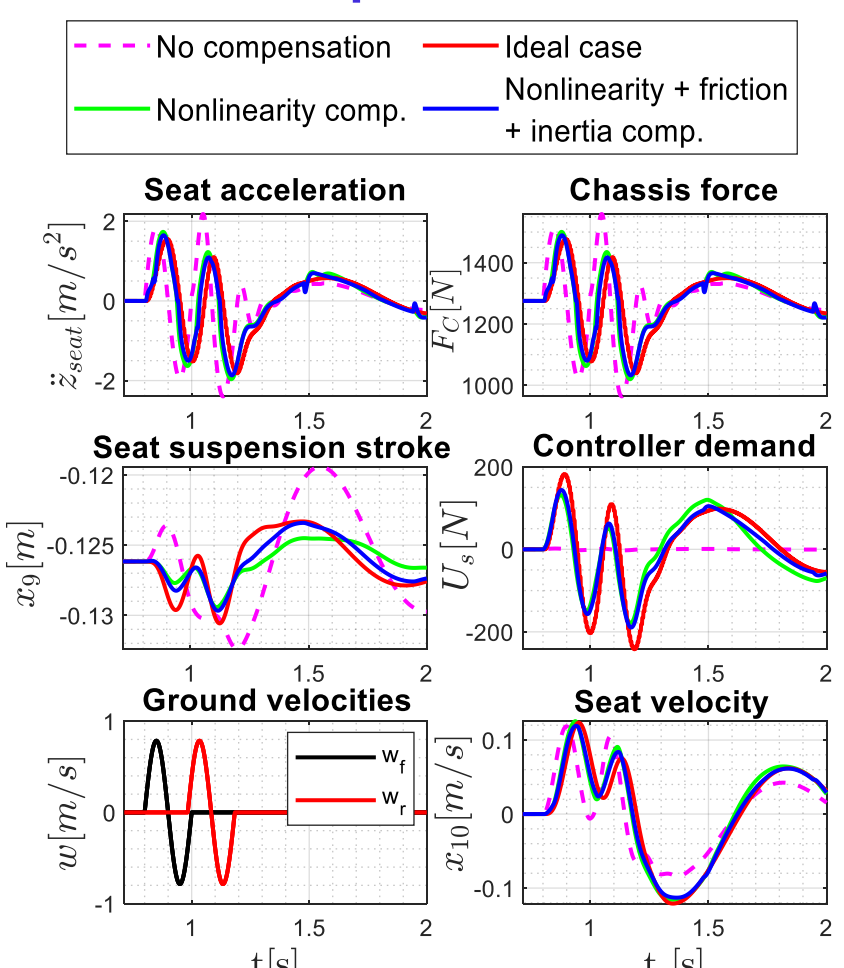


LQR design

$$J_{LQR} = E(\ddot{z}_{seat}^2 + q_1 x_9^2)$$

$T_s = 5$ ms

Effect of low-level control active seat control performance



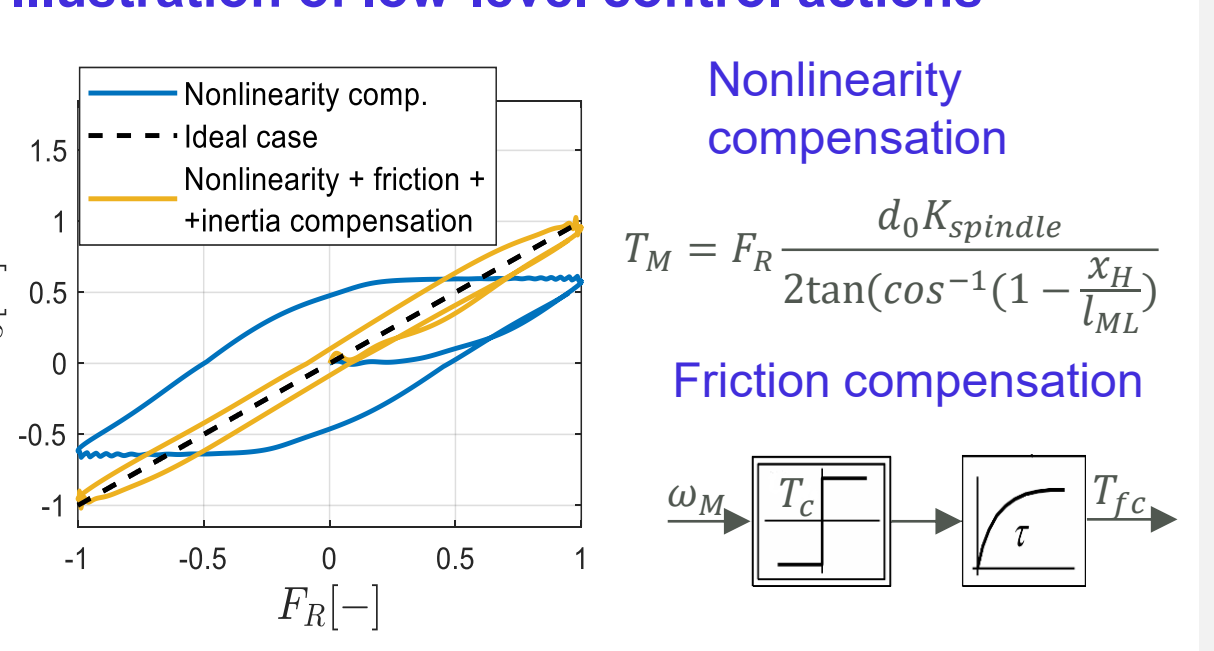
MPC design

$$J_{MPC} = E(\ddot{z}_{seat}^2), \quad u_{min} \leq u \leq u_{max}$$

$T_s = 5$ ms, $N = 100$, $-x_{9,limit} \leq x_9 \leq x_{9,limit}$

- RMS seat acceleration minimized; seat suspension stroke penalized
- YALMIP implementation (quadprog solver)
- Full feedback case (both seat and chassis variables are fed back to controller)

Illustration of low-level control actions



Acknowledgements

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