Active Joint Connections

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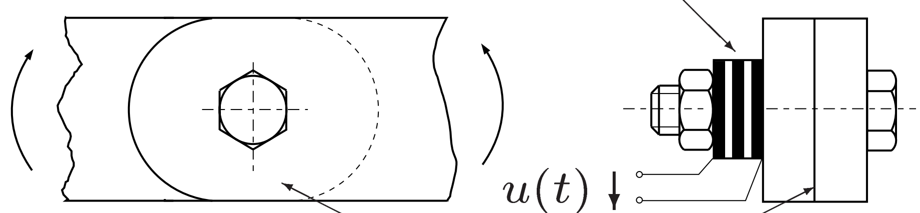
Idea of an Active Joint

Using the normal force as control variable, one obtains a controllable friction moment.
Varying the normal force by means of a piezoelectric stack disc.

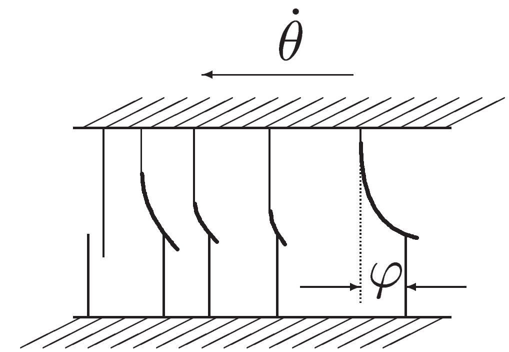


Active control theory will be used to vary properties of a passive element!
Applying active control theory to vary the normal force and, thus, the friction force $\rightsquigarrow$ **Semi-Active Friction Damping.**

The idea of the *Active Joint* is patented in Germany by L. Gaul under *DE 197 02 518*.

LuGre-Friction Model

Friction interface is thought of as a contact between bristles.



$$
\begin{aligned}
M_\mathrm{f} &= r \overbrace{F_\mathrm{N}}^{\equiv u} (\sigma_0\varphi + \sigma_1\dot\varphi + \sigma_2\dot\theta) \\
&=: r\,u\,\mu(\varphi,\dot\varphi,\dot\theta), \\
\dot\varphi &= \dot\theta - \sigma_0 \frac{|\dot\theta|}{g(\dot\theta)}\,\varphi \\
g(\dot\theta) &= M_\mathrm{c} + M_\Delta \exp\left(-\left(\dot\theta/\dot\theta_\mathrm{s}\right)^2\right)
\end{aligned}
$$

- F_N **actuator variable** i. e. u
- $\dot\theta$ relative velocity
- φ average deflection of the bristles
- σ_i, M_j, v_s, r model parameters

Note: μ represents a kind of a state dependent friction coefficient.

Some Notable Properties of the LuGre-Model

- Static behavior:

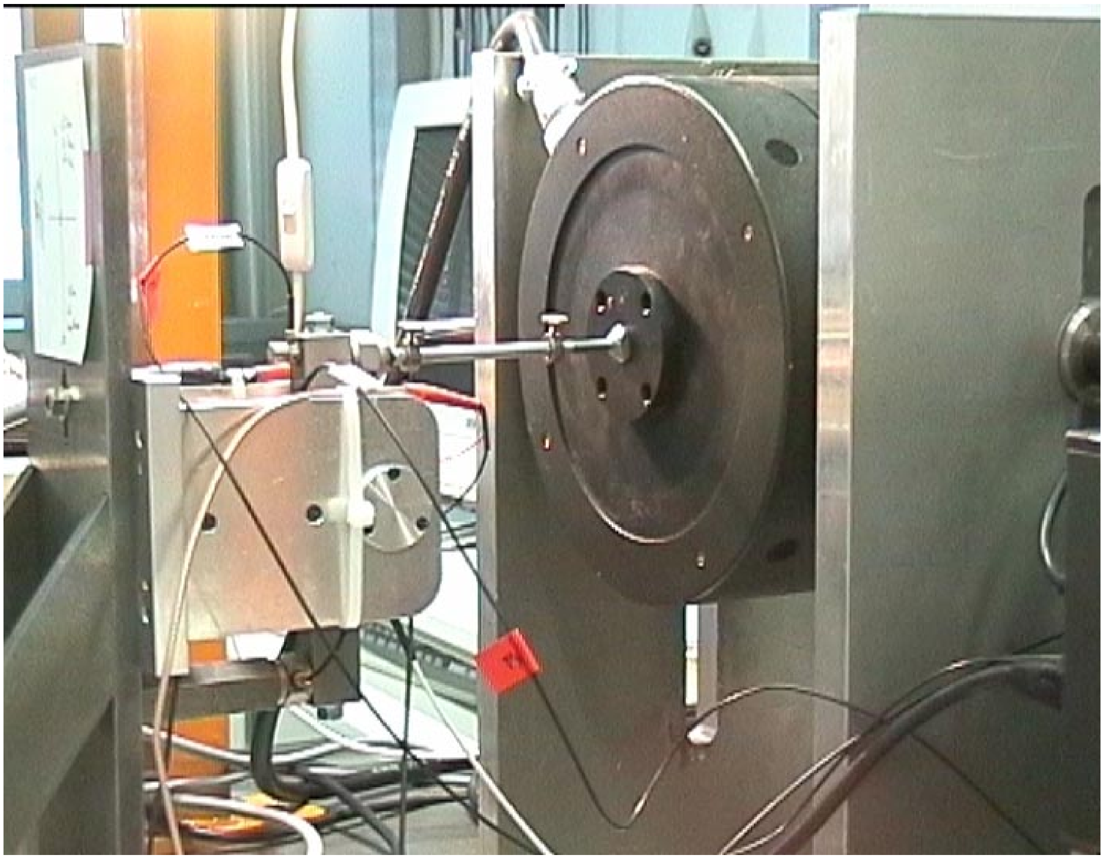
$$M_{\mathrm{ss}} = \left[M_{\mathrm{c}} + M_{\Delta}\ \exp\left(-(\dot{\theta}/\dot{\theta}_{\mathrm{s}})^2\right)\right]\ \mathrm{sgn}(\dot{\theta}) + \sigma_2\dot{\theta}$$

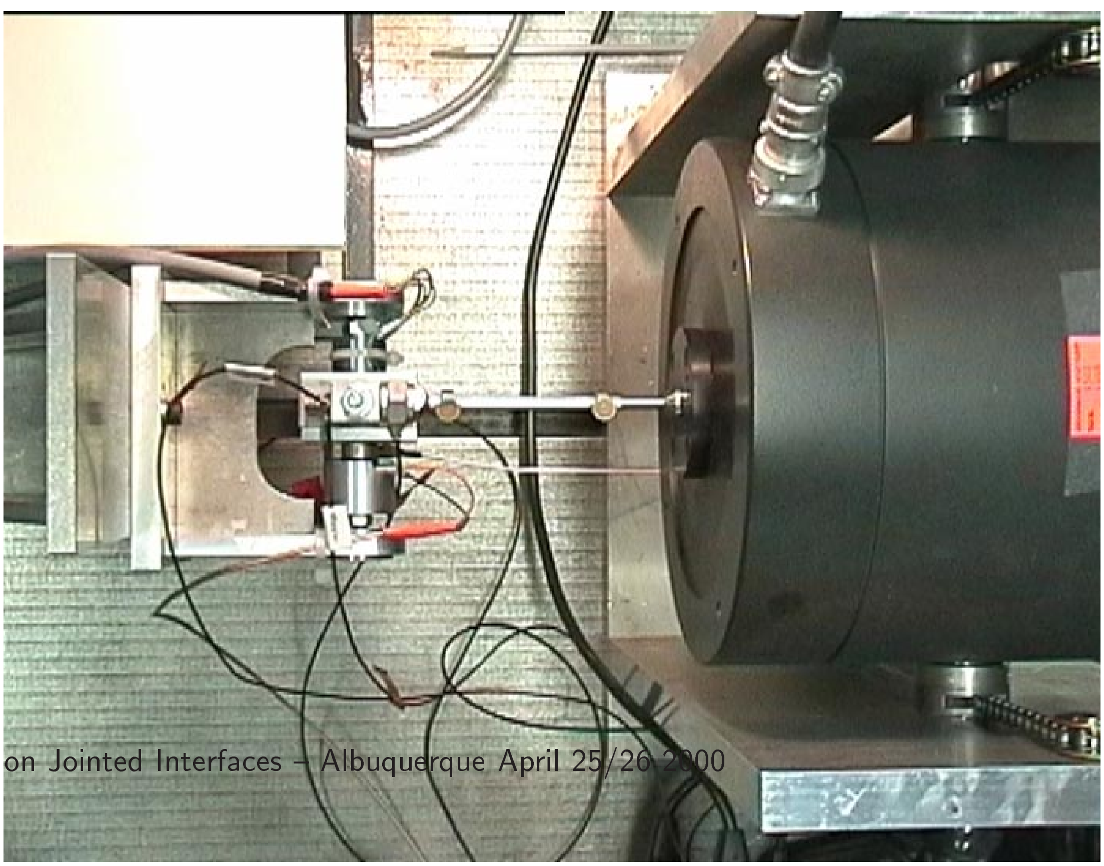
$\leadsto$ Four *static* parameters: M_{c}, M_{Δ}, $\dot{\theta}_{\mathrm{s}}$, and σ_2.

- Two *dynamic* parameters due to the dynamic bristle deflection:
  $\leadsto$ σ_0 (stiffness of the bristles) and σ_1 (damping of the bristles)

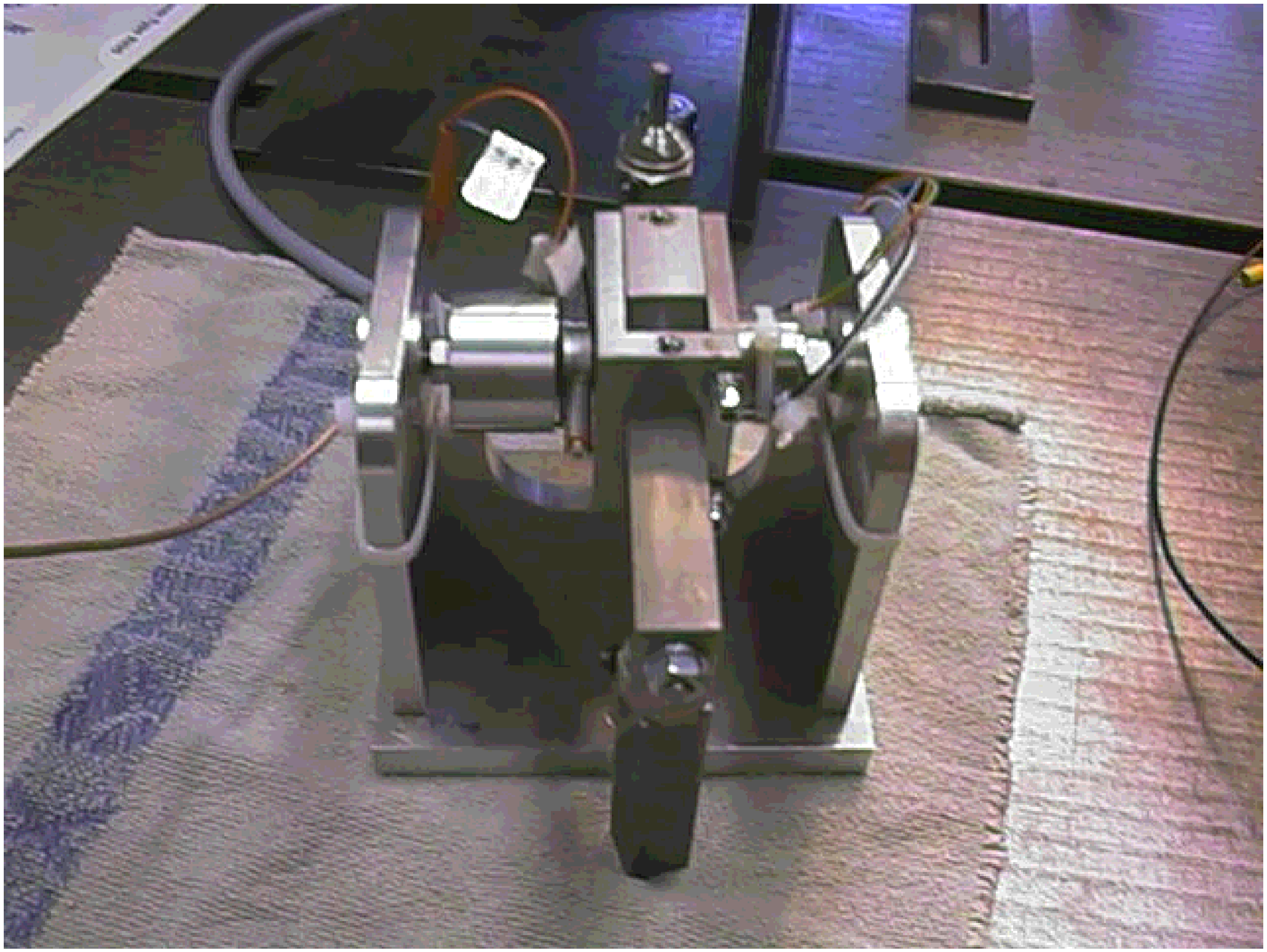
- Boundedness of the bristle deflection *i.e.* φ.

Experimental Setup





Active Joint



System Identification

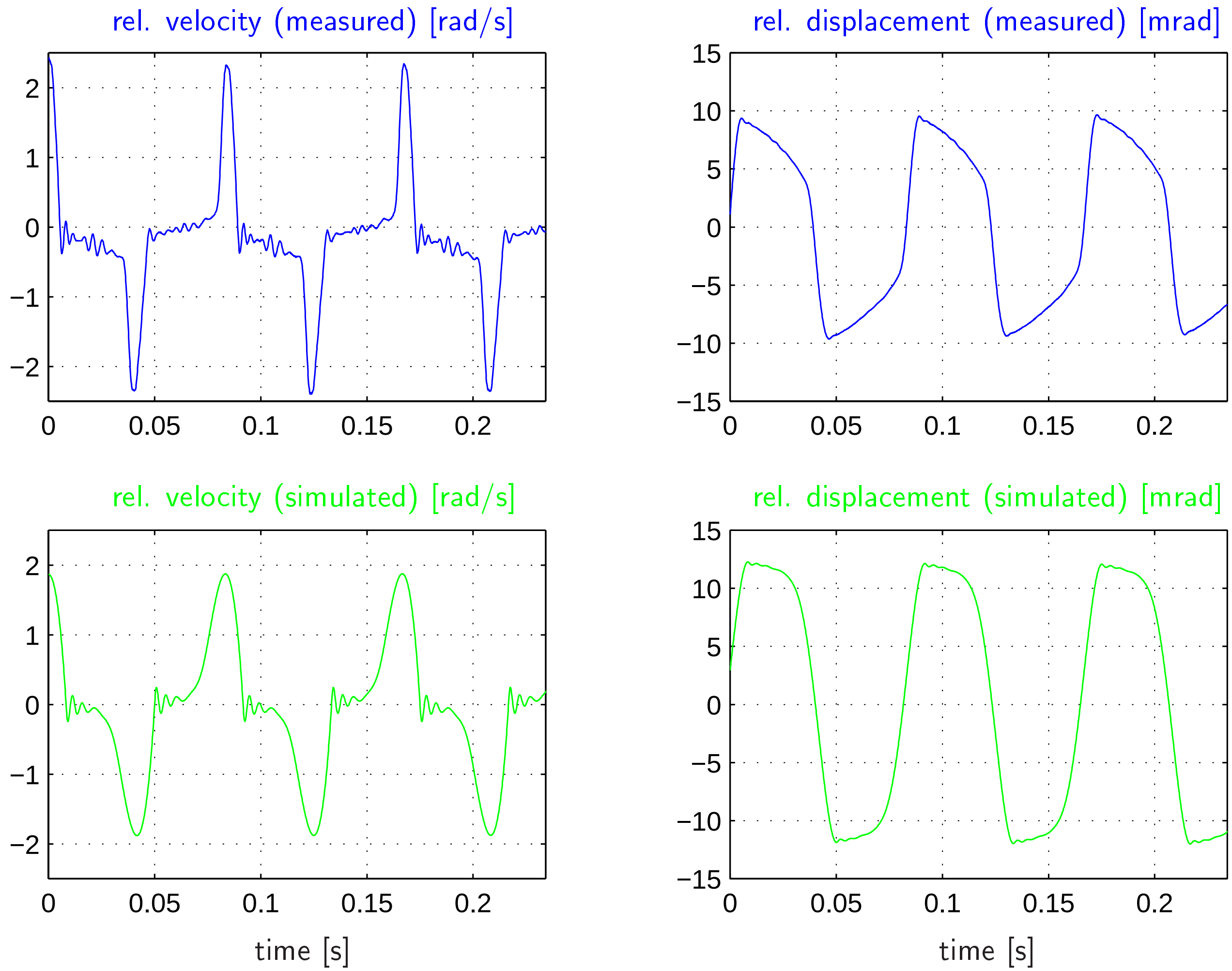
Model Equation

$$
\begin{aligned}
J\ddot{\theta} + d\dot{\theta} + c\theta + M_{\mathrm{f}} &= \rho f_{\mathrm{ext}} \\
M_{\mathrm{f}} &= r\, F_{\mathrm{N}}(\sigma_0 \varphi + \sigma_1 \dot{\varphi} + \sigma_2 \dot{\theta}) \\
\dot{\varphi} &= \dot{\theta} - \sigma_0 \frac{|\dot{\theta}|}{g(\dot{\theta})}\, \varphi \; g(\dot{\theta}) = M_{\mathrm{c}} + M_{\Delta}\, \exp\left(- \left(\dot{\theta}/\dot{\theta}_{\mathrm{s}}\right)^2 \right)
\end{aligned}
$$

- The four *static* parameters: M_{c}, M_{Δ}, $\dot{\theta}_{\mathrm{s}}$, and σ_2 are estimated using nonlinear least-square techniques with a minimal normal force in the friction interface of $F_{\mathrm{N}} = 310\,$N,
  $\rightsquigarrow$ macro slip.

- The two *dynamic* parameters σ_0 and σ_1 are identified from data when the normal force was at it's maximum, *i.e.* $F_{\mathrm{N}} = 690\,$N,
  $\rightsquigarrow$ micro slip.

System Identification



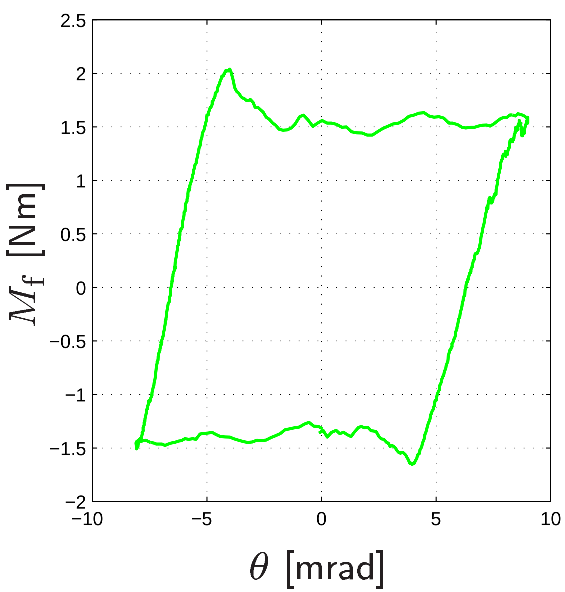
Controller Design

A controller was designed using Lyapunov-technique in order to maximize the energy dissipation due to friction in the joint.

$$V = \frac{1}{2}J\dot{\theta}^2 + \frac{1}{2}c\theta^2 \quad \rightsquigarrow \quad u = -\kappa\frac{\mathrm{d}V}{\mathrm{d}t}$$

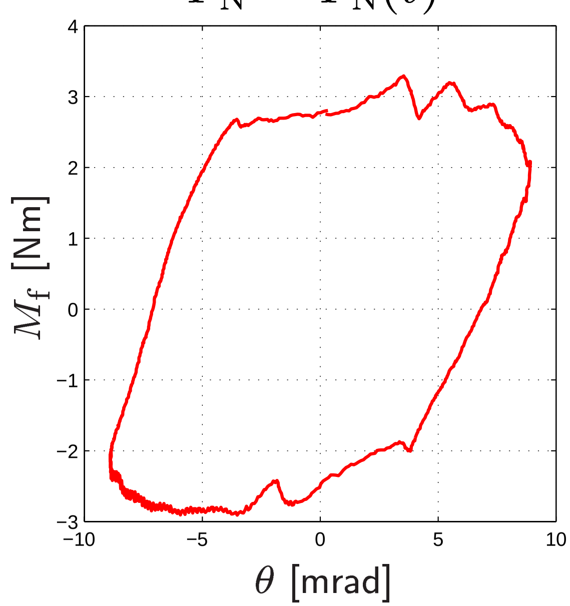
$W_\mathrm{d} = 38.9\,\mathrm{Nm\cdot\ mrad}$

$F_\mathrm{N} = 310\mathrm{N}$



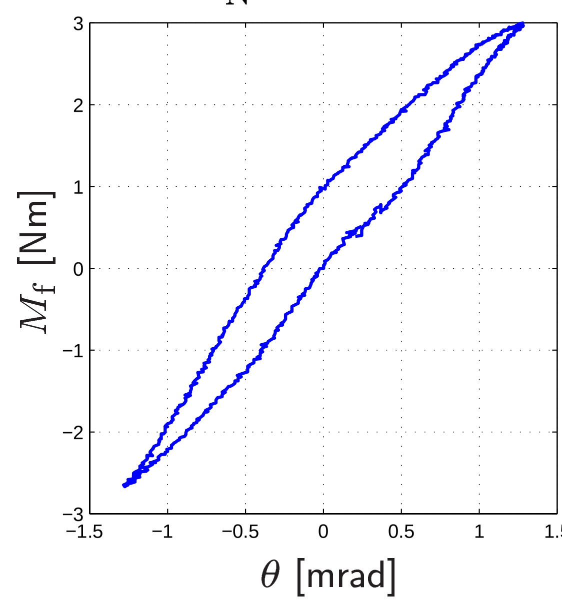
$W_\mathrm{d} = 72.7\,\mathrm{Nm\cdot\ mrad}$

$F_\mathrm{N} = F_\mathrm{N}(t)$

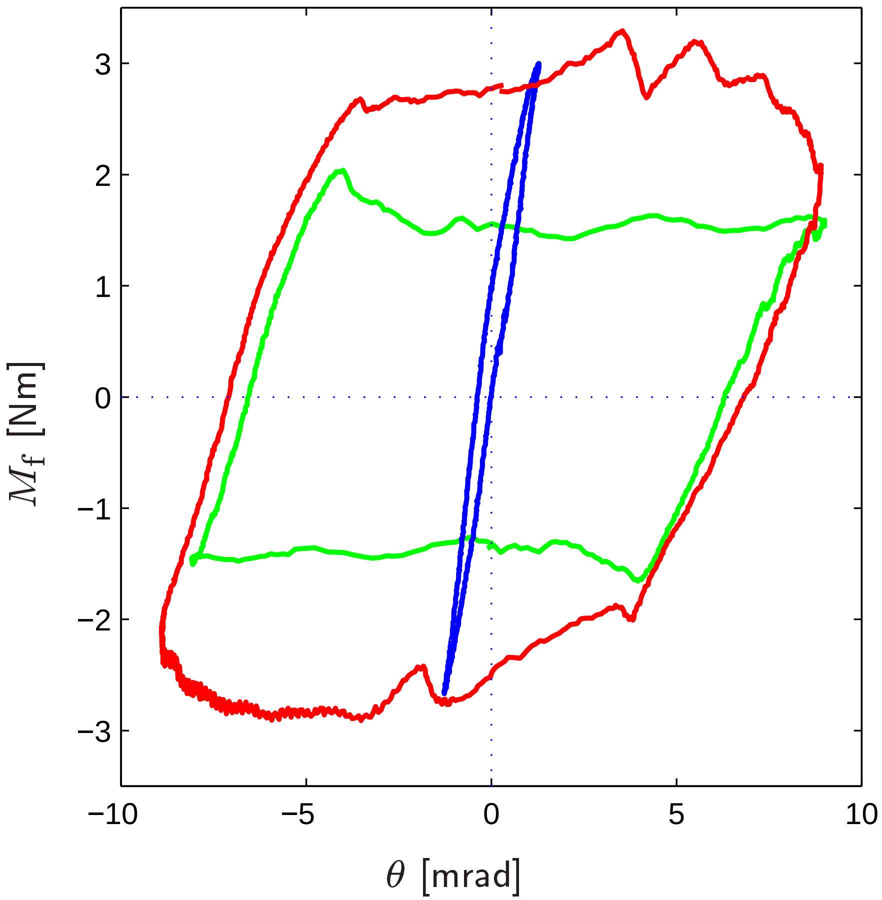


$W_\mathrm{d} = 1.6\,\mathrm{Nm\cdot\ mrad}$

$F_\mathrm{N} = 690\mathrm{N}$



Friction Hysteresis of the Active Joint



$F_{\mathrm{N}} = 690\mathrm{N}$

$F_{\mathrm{N}} = 310\mathrm{N}$

$F_{\mathrm{N}} = F_{\mathrm{N}}(t)$ controlled

Conclusion

- An active joint was investigated by controlling the normal force in the friction interface: semi-active friction damping.
  $\leadsto$ Loss of complete controllability.

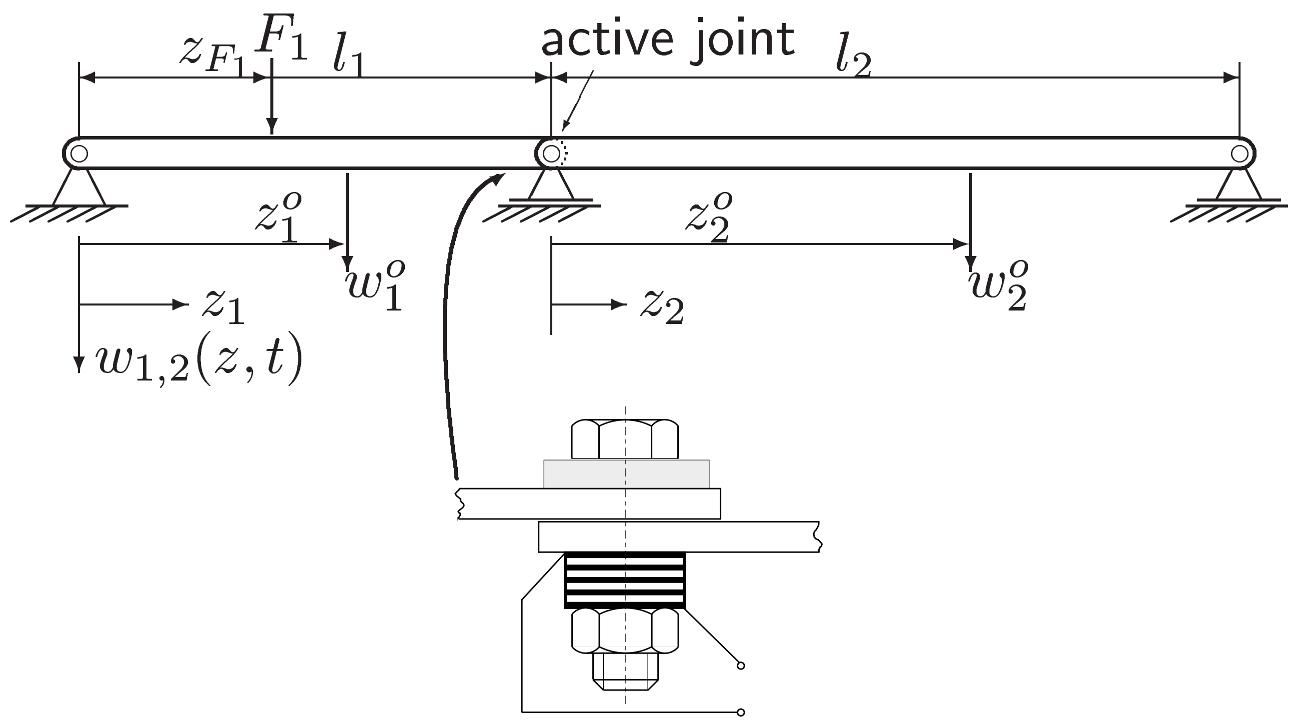
- As energy is always dissipated, there will be no spillover instability caused by the controller.

- Semi-active joints are less massive than fully active damping concepts.

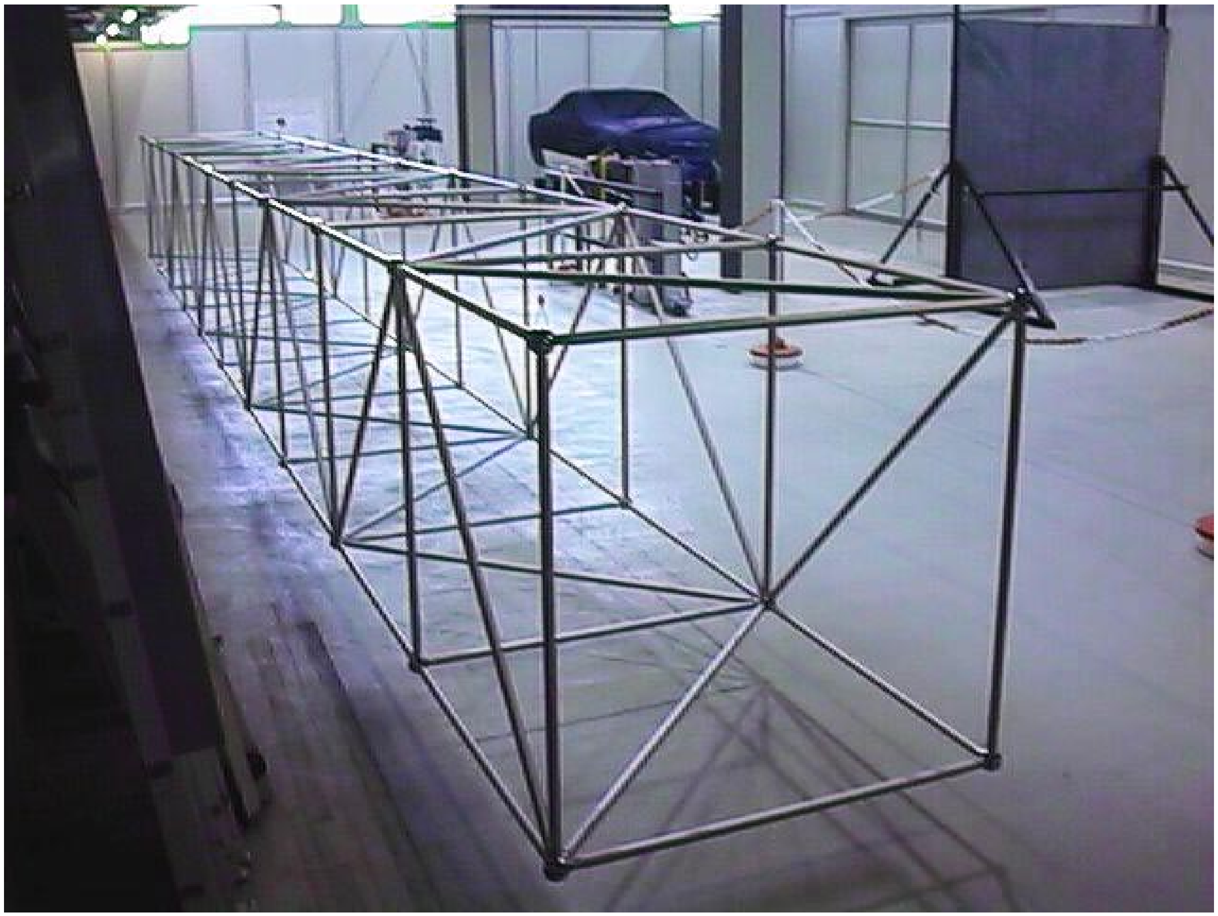
- Numerous joint connections available in LSS.

Future Work

- Experimental evaluation of the active joint connection in a simple flexible structure (Two Beam Structure).



- Implementation in a large flexible structure.



An Active Joint in a Flexible Structure