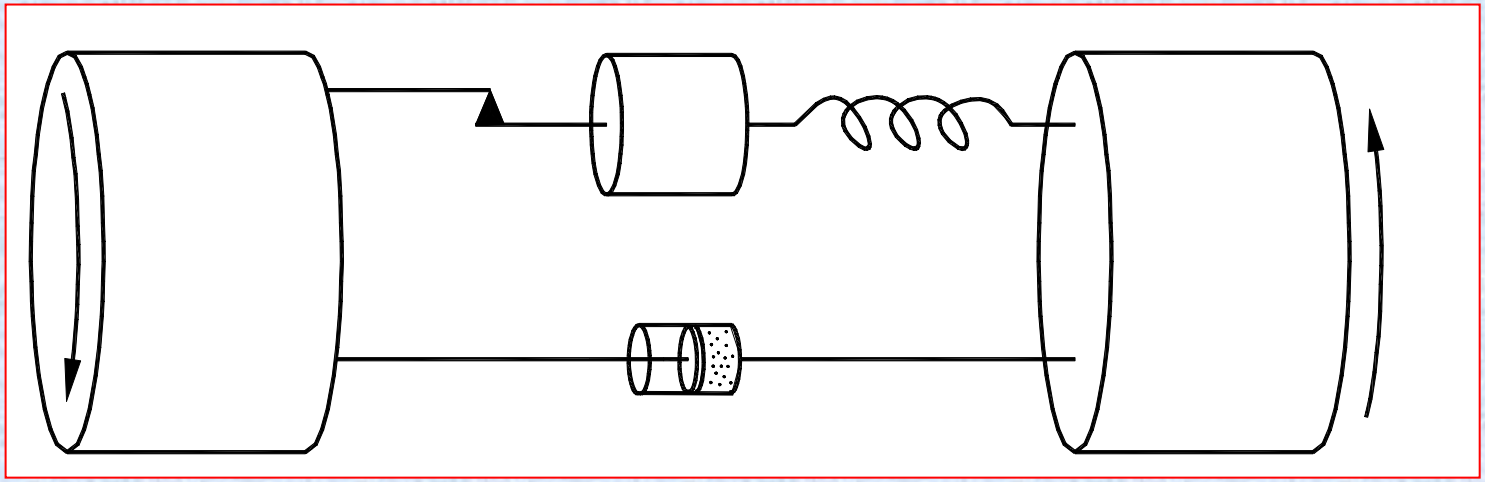
Dynamic Analysis of Dry Friction Paths in Torsional Systems

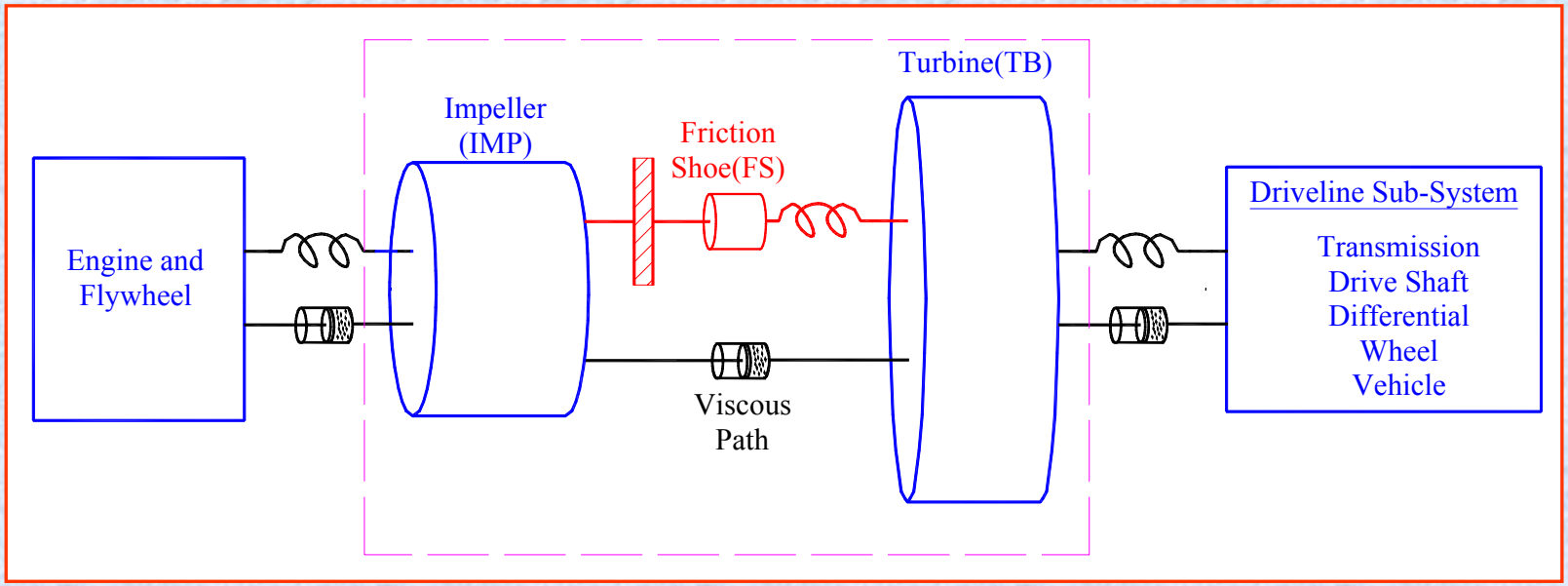
With Focus on Automotive Torque Converter Clutch

C. Duan and R. Singh

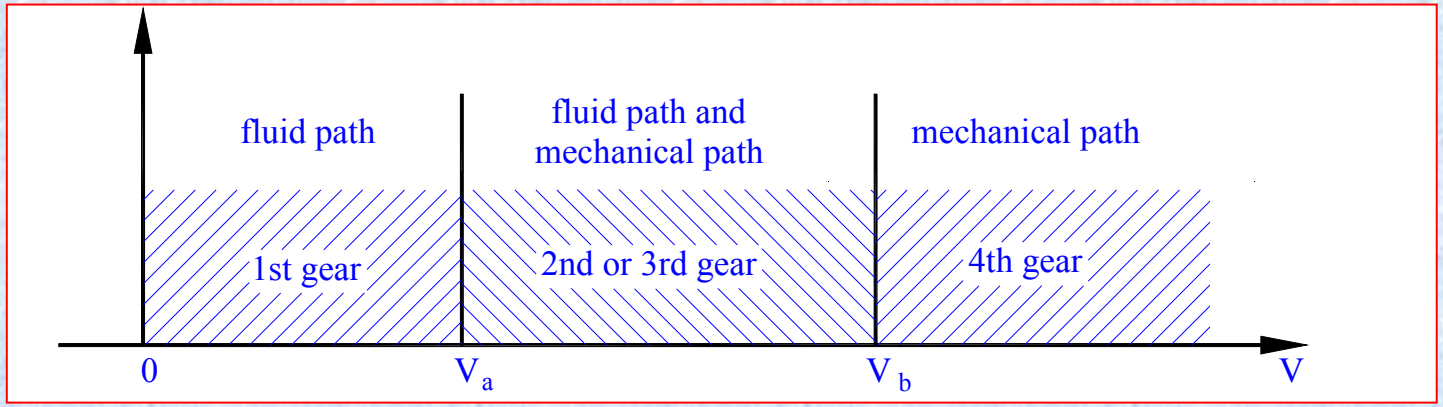


Acoustics and Dynamics Lab
Center for Automotive Research
The Ohio State University

Automotive Drive Train: System and Operating Conditions

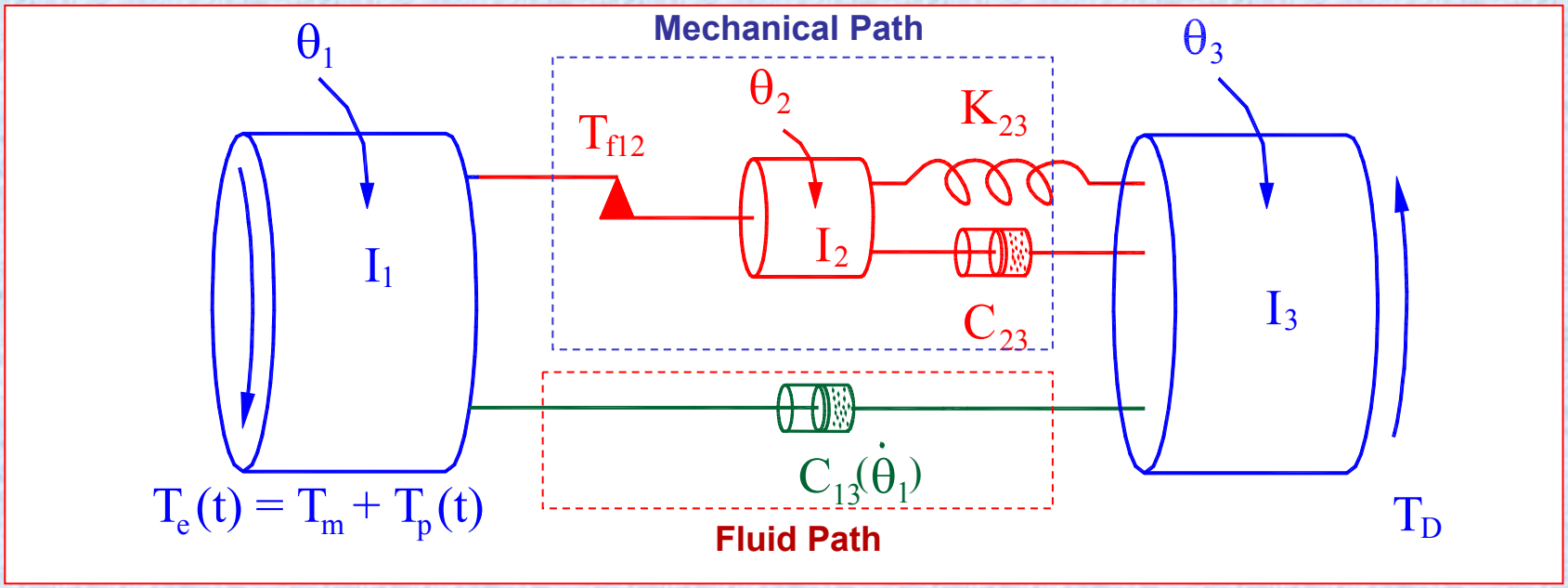


Schematic Model



TCC Operating Conditions

Reduced Order System



I_1: Flywheel and Impeller I_2: Friction Shoe Assembly I_3: Downstream Driveline

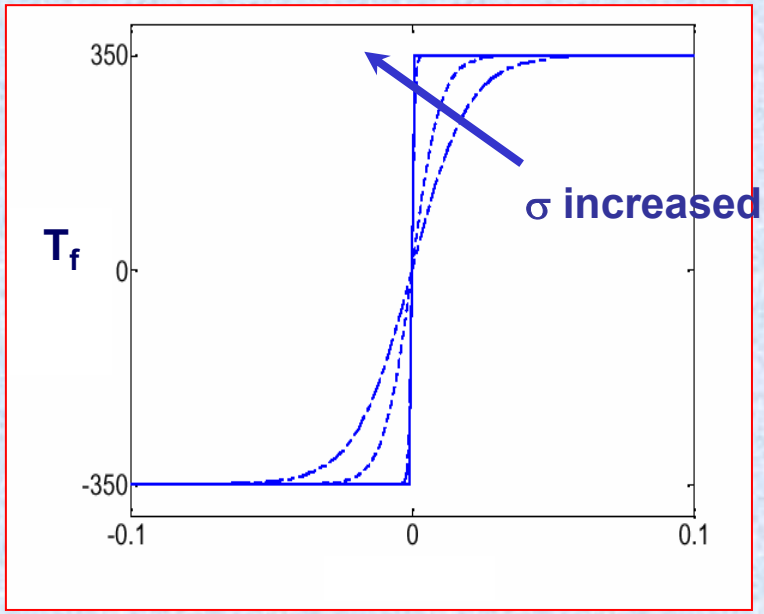
- Engine torque: combination of mean and pulsating terms
- Dry friction clutch: non-linear torque w.r.t interfacial relative velocity
- Fluid (viscous) path: torque transmitted w.r.t. engine speed

THE OHIO STATE UNIVERSITY

ADL

Smoothened vs. Discontinuous Coulomb Friction Formulation

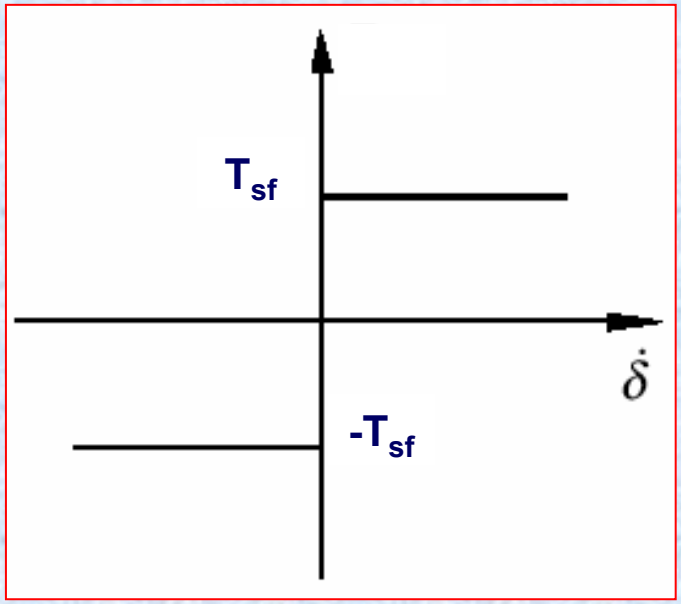
Continuous and Non-linear:



σ = conditioning factor

- Active friction torque w.r.t. relative velocity

Discontinuous and Piecewise Linear:

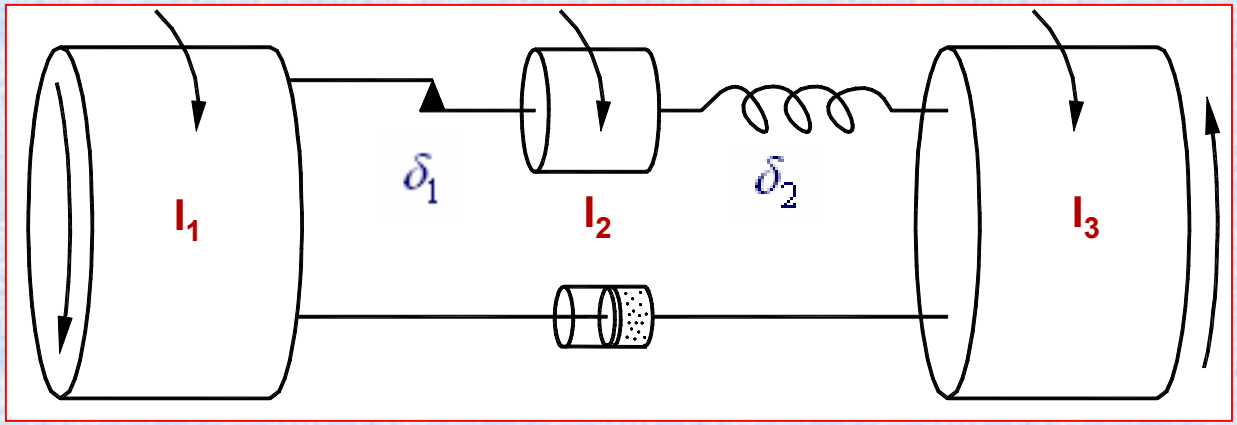


- Passive friction torque w.r.t. relative velocity

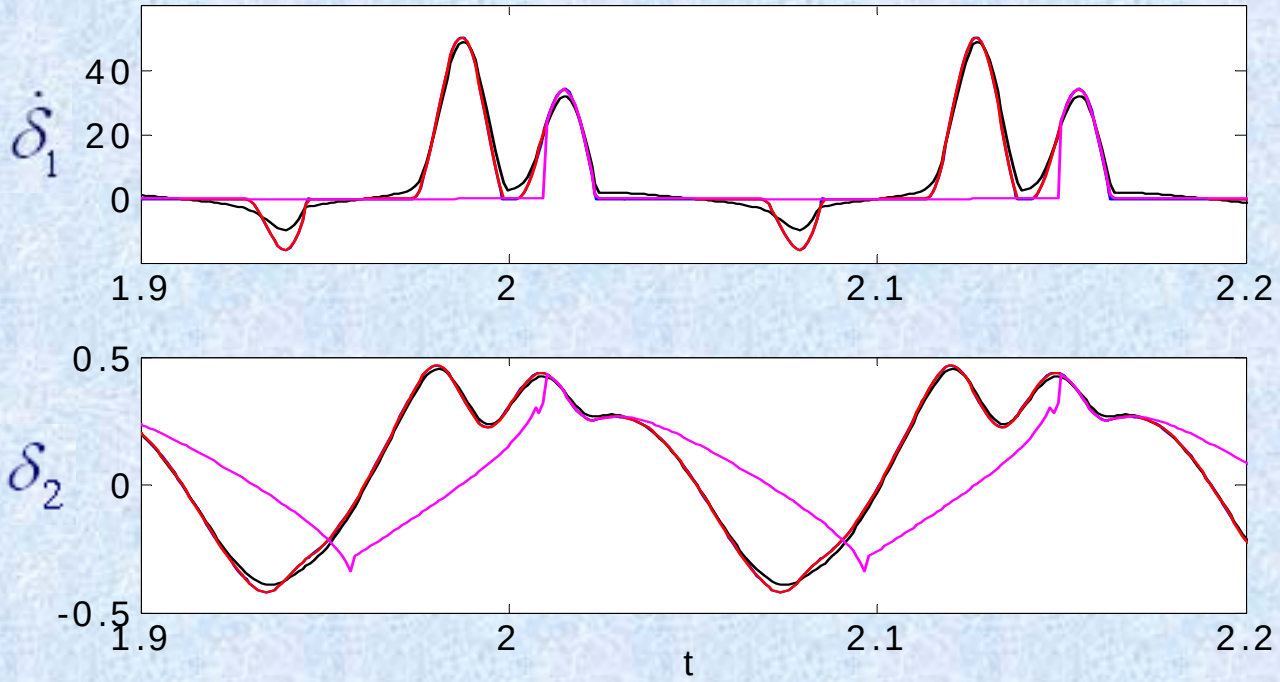
THE OHIO STATE UNIVERSITY

ADL

Smoothened vs. Discontinuous Friction Formulations



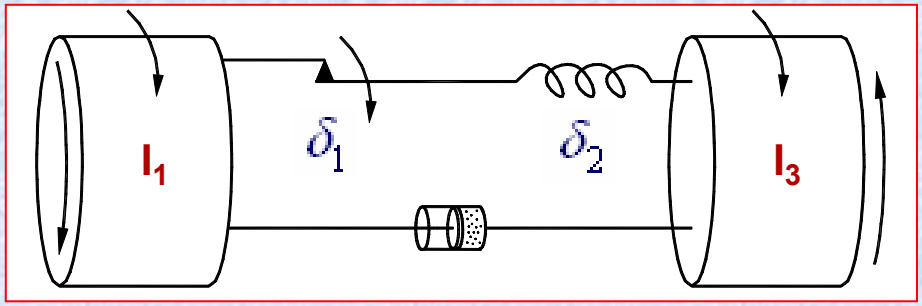
- **Time Domain Responses:**



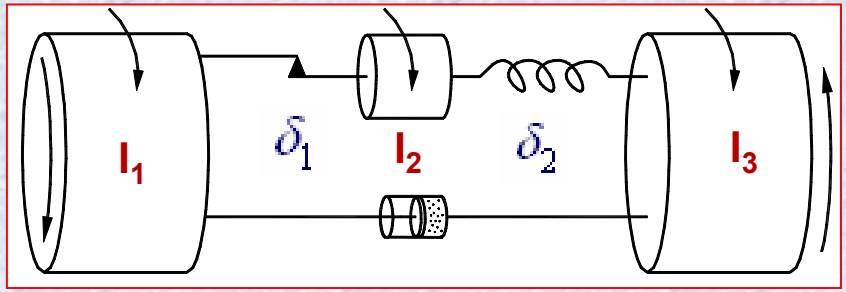
discontinuous friction; smoothened σ =0.5; smoothened $\sigma = 10^2$; smoothened $\sigma = 10^3$

Effect of Secondary Mass: 2DOF vs. 3DOF Systems

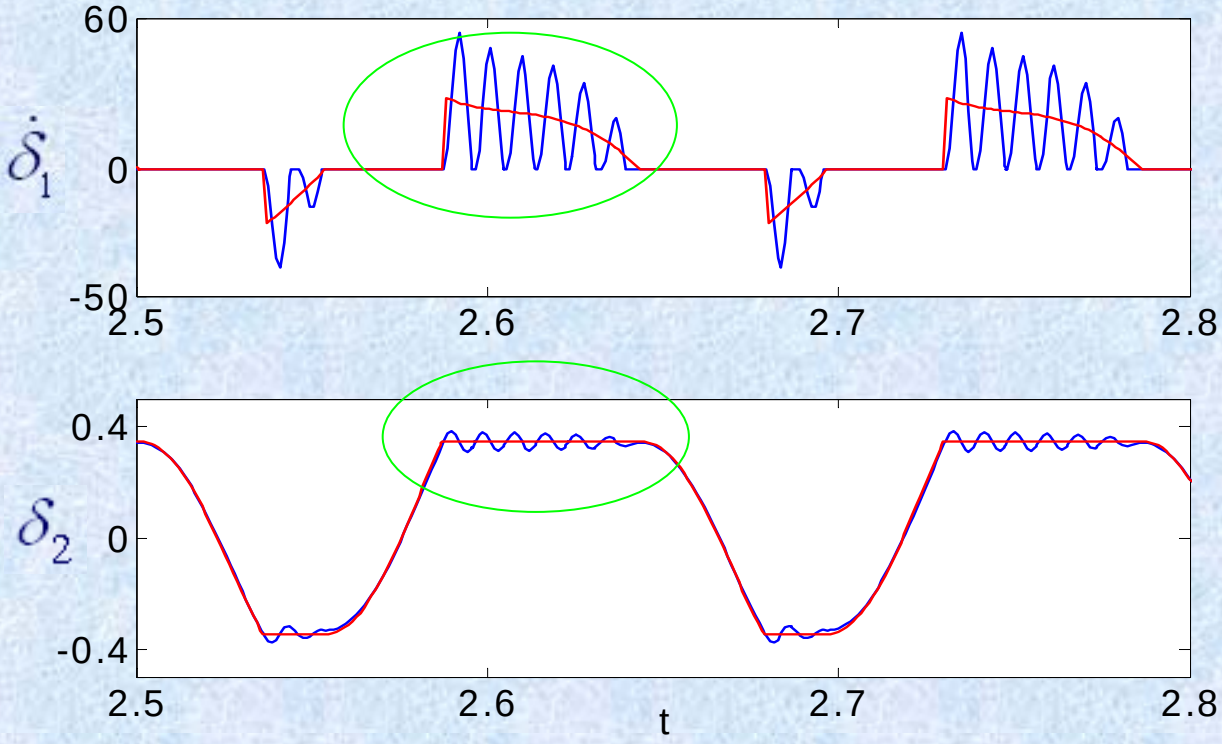
2DOF ($I_2 = 0$)



3DOF ($I_2 \neq 0$)

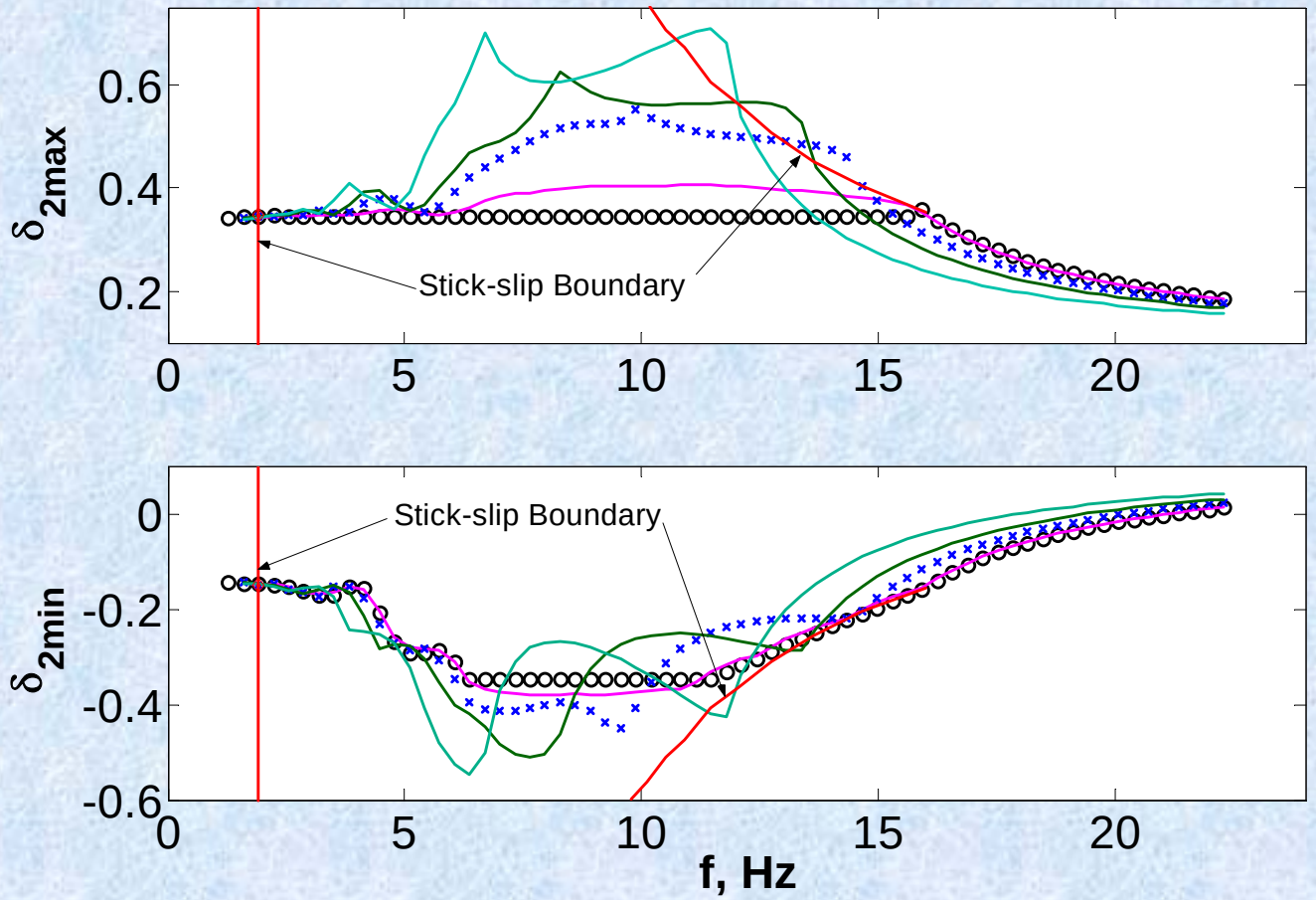


- **Comparison of Time Histories**



Key: ___ $I_2/I_1 = 0$; ___ $I_2/I_1 = 0.01$

Frequency Response Characteristics: 2DOF vs. 3DOF System



Key:

o o o $I_2/I_1 = 0$ (2DOF)

x x x $I_2/I_1 = 0.1$

$I_2/I_1 = 0.4$

$I_2/I_1 = 0.01$

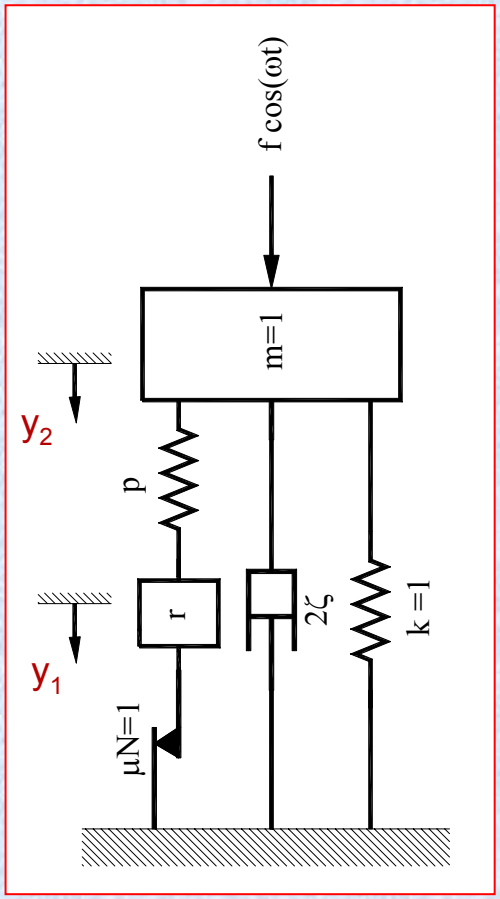
$I_2/I_1 = 0.2$

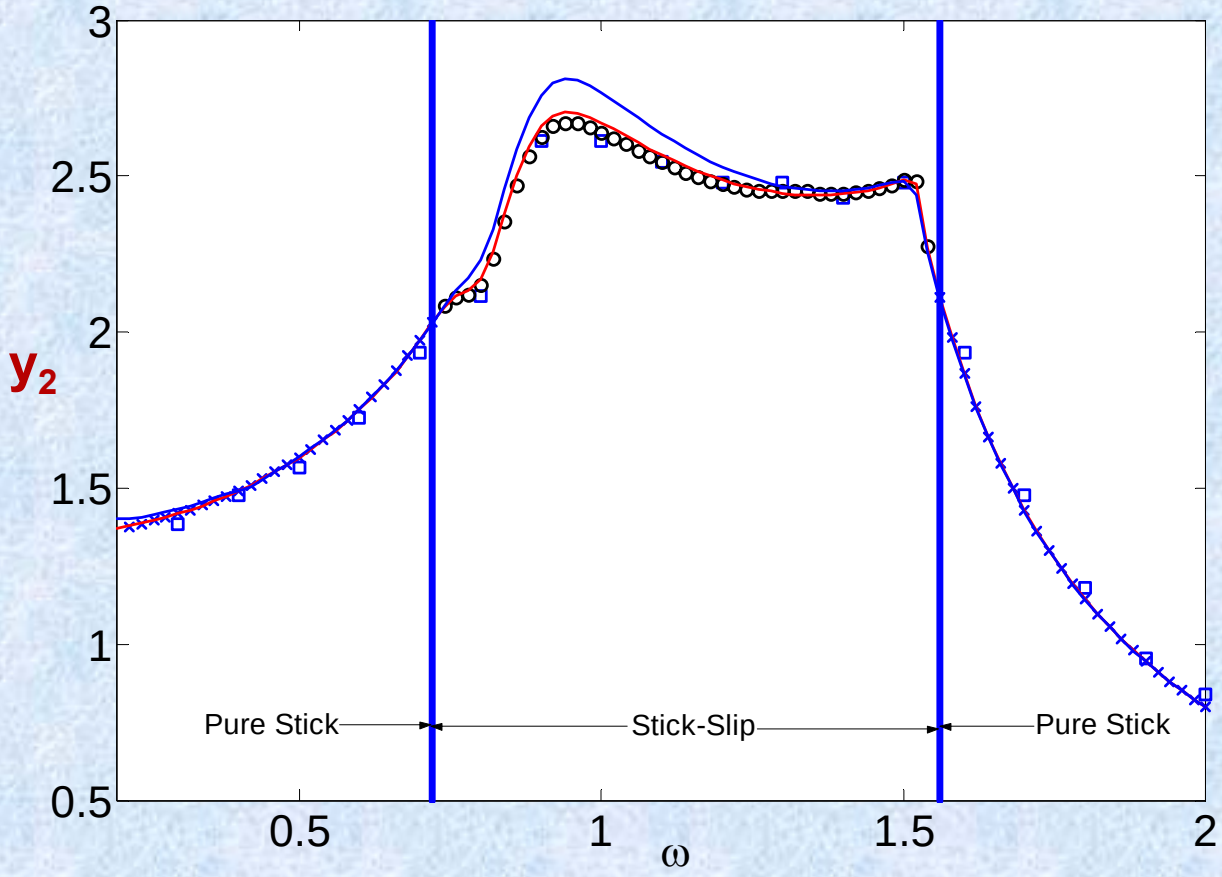
Boundaries based on the linear theory

THE OHIO STATE UNIVERSITY

ADL

Validation: Ferri and Heck's Analysis (1995)





Turbine Blade Friction Damper

Key:

x x x pure stick solution

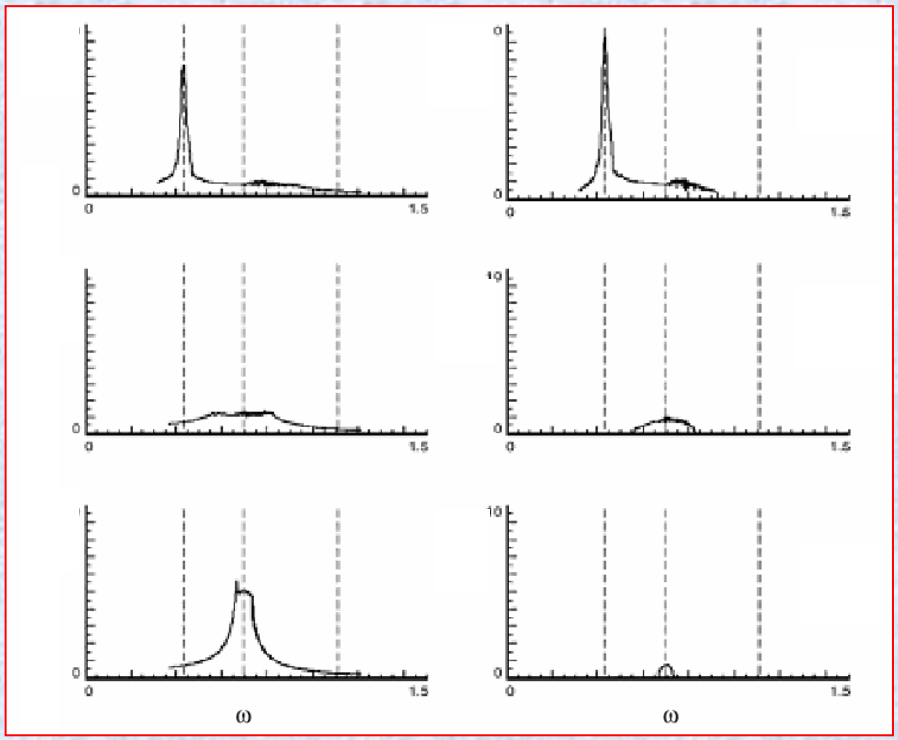
o o o discontinuous model

___ smoothened friction σ = 50

___ smoothened friction σ = 10

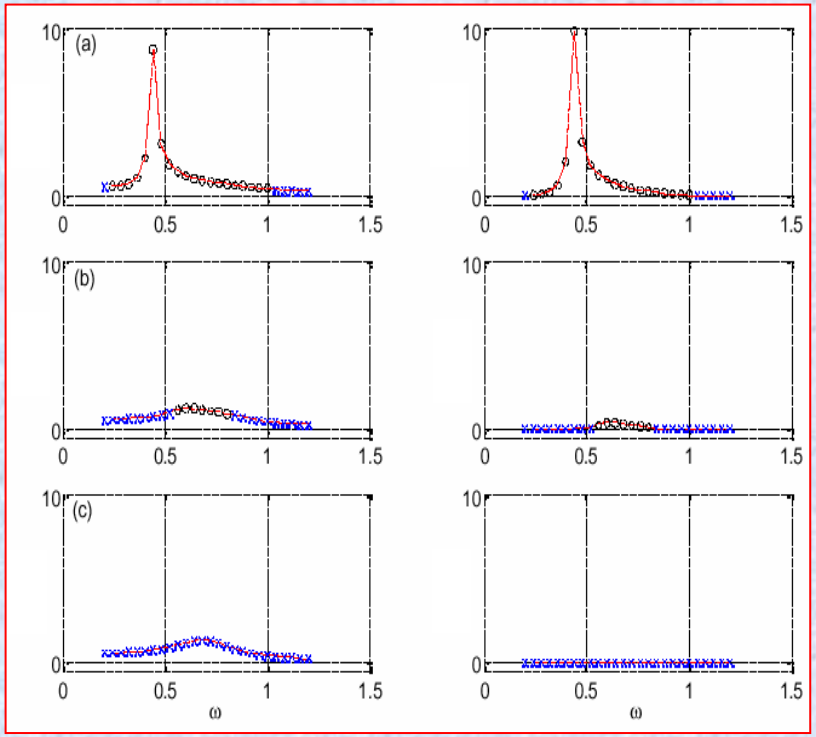
□ □ □ Ferri and Heck's

Validation: Hartung et. al. Experiment (2001)

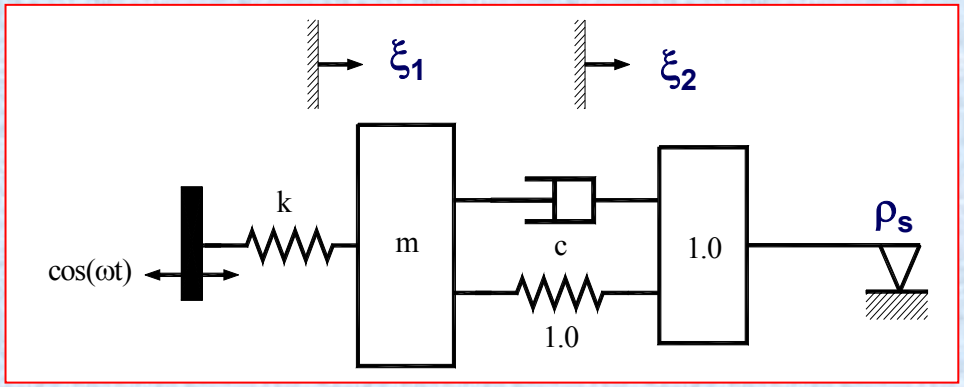


Hartung et. al. Experiment (2001)

$\rho_s \uparrow$



Our Predictions



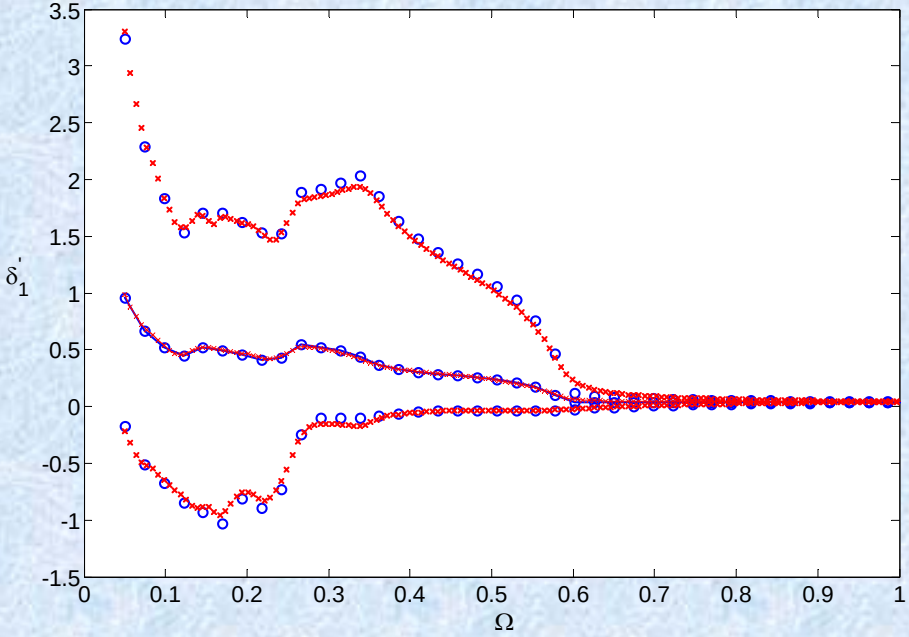
Key:

x x x pure stick solution

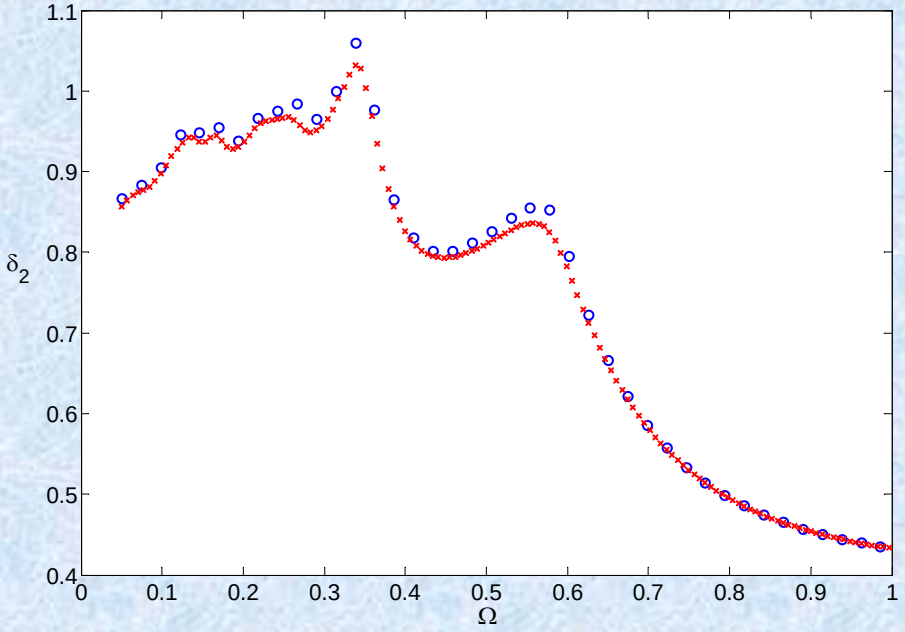
o o o discontinuous solution

___ smoothened friction $\sigma = 50$

Non-Linear Frequency Response Characteristics
Appearance of Super-Harmonics



Velocity (θ_1- θ_2): max-mean-min



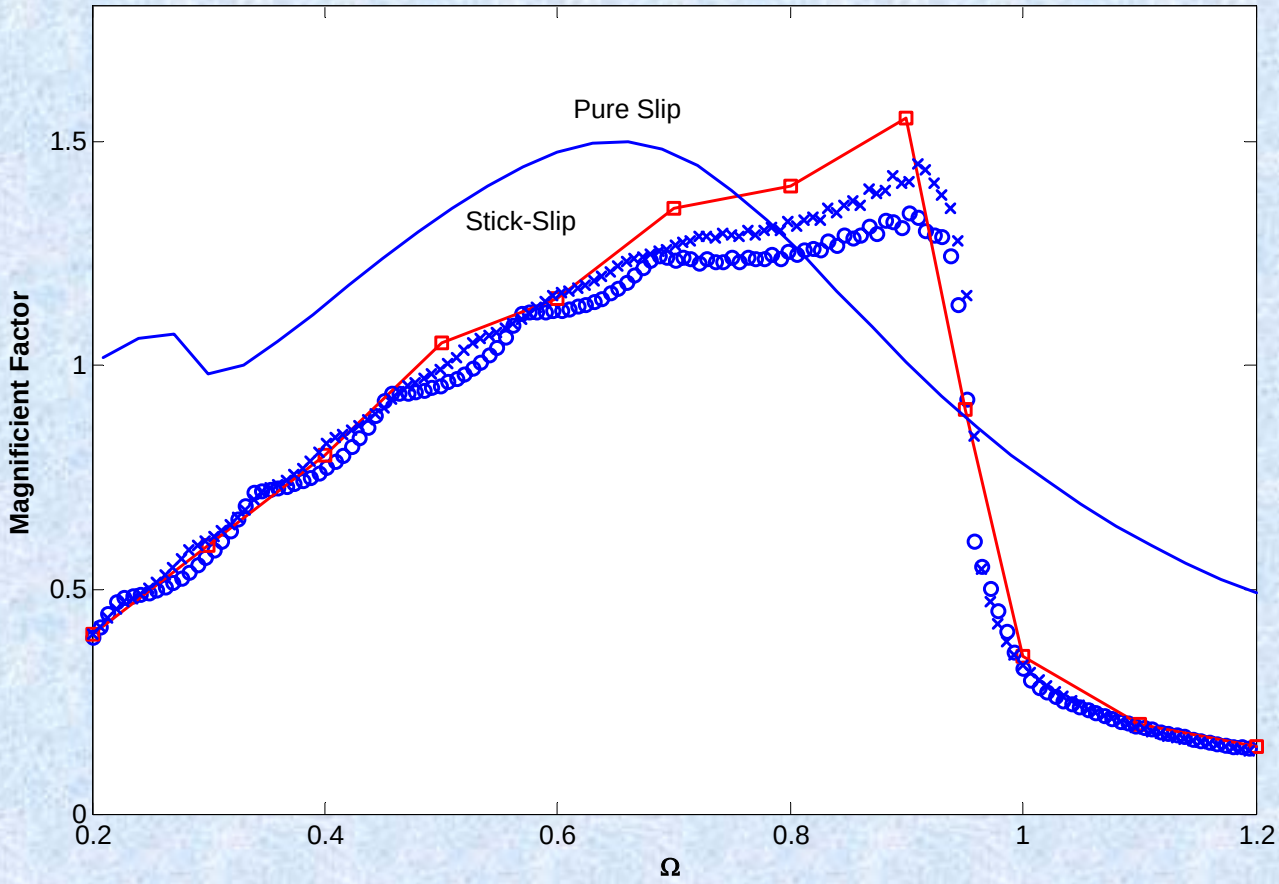
Displacement (θ_2): rms

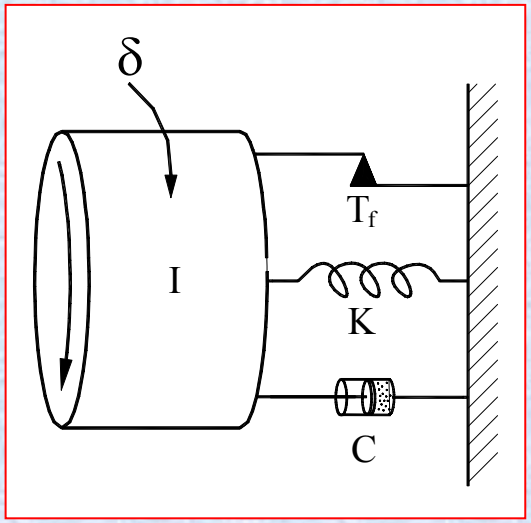
Key: o o o Broyden; x x x Newton Raphson

THE OHIO STATE UNIVERSITY

ADL

Comparison with Den Hartog's Model





- □-: Den Hartog's model

ooo: MHMB(12 Harmonics)

xxx: MHBM(24 Harmonics)

--- : slip motion boundary

THE OHIO STATE UNIVERSITY

MHBM = Multi-term Harmonic Balance Method

ADL

Publications

1. C. Duan and R. Singh, *Dynamics of a 3DOF Torsional System with a Dry Friction Controlled Path*, submitted to the Journal of Sound and Vibration, 2003.

2. C. Duan and R. Singh, *Super-Harmonics in a Torsional System with Dry Friction Path Subject to Harmonic Excitation under a Mean Torque*, submitted to the Journal of Sound and Vibration, 2004.

3. C. Duan and R. Singh, *Effect of Time-Varying Dry Friction on Transient and Steady-State Responses of a Torsional System*, in preparation for the Journal of Sound and Vibration, 2004.