Rensselaer Polytechnic Institute
Mechatronics Research Program

Identification of Backlash, Friction and Compliance in Machine Tool Drive Trains

National Science Foundation
Mechatronics in Machine Tools Grant

Julian A. de Marchi, G.R.T.
Dr. Kevin C. Craig, Co-P.I. & Thesis Advisor

Department of Mechanical Engineering, Aeronautical Engineering & Mechanics

Motivation

- **Drive nonlinearities cause machining errors**
  — cause of positioning error in workpiece cutting and
  — exacerbated when machining at high speeds and cu
  — cause of damage to workpiece and cutting tools

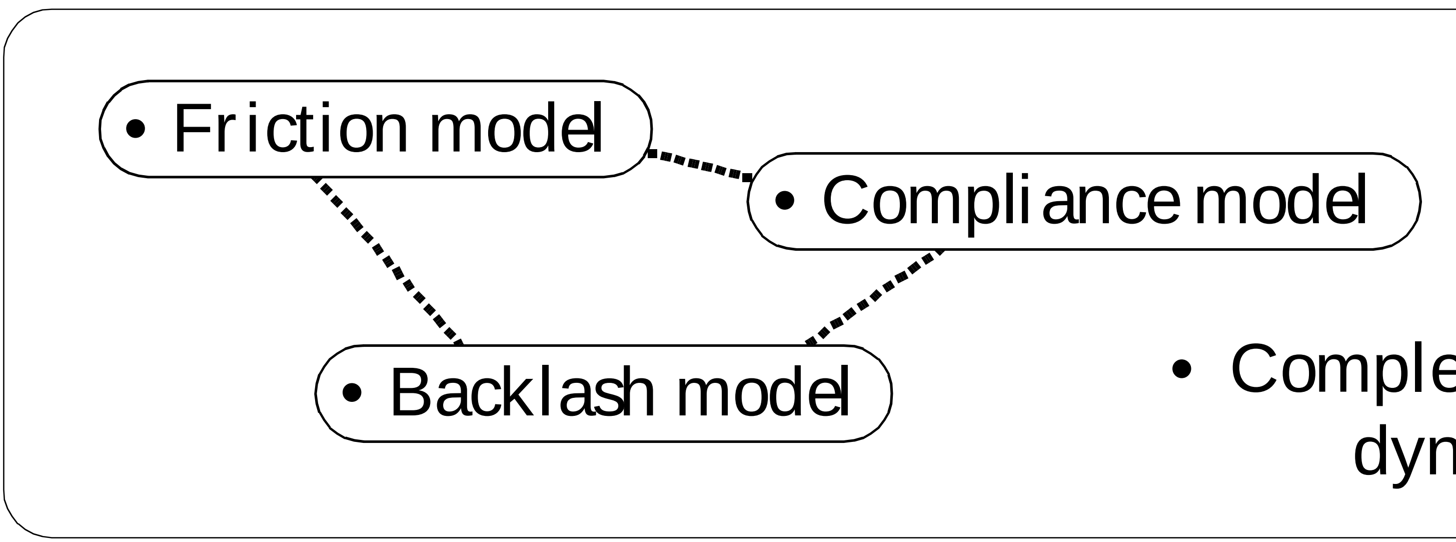
- **Frictional errors**
  — thermal expansion
  — stick-slip friction (stiction)

- **Back**
  — tol
  — im
  — pit

- **Compliance error**
  — vibration
  — energy storage and relea

Objectives

- Using a generalized model of drive nonlinearit
  tools may be controlled more precisely and a
  — model nonlinear friction, backlash and compliance
  — model dynamic interaction between the componen
  — apply model to, and verify using, data from actual



Overall Approach

- Develop analytical model
  - — model nonlinear friction, backlash & compliance c

- Develop system identification
  - — verify system ID procedure on simu

- Identify machine tool dynamics
  - — test system ID on test bed and actual machine
  - — corroborate known parameter values and pul

Technical Details: Fric

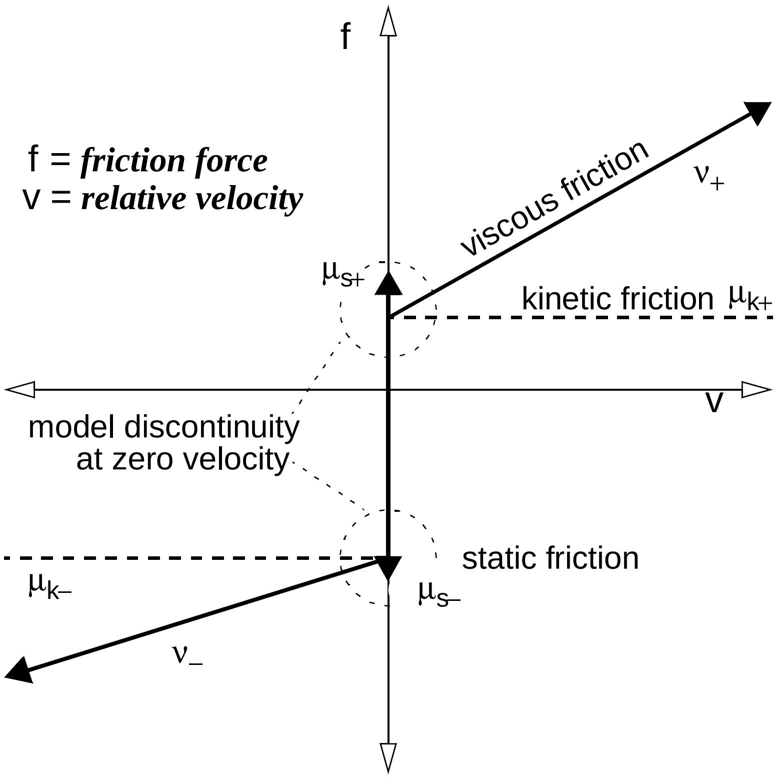
- Static phenomena
  - normal friction
    (increases with normal load)
  - rising friction
    (increases with static contact time)

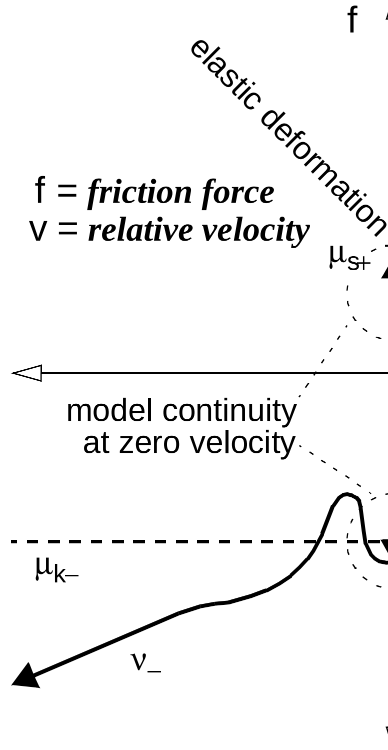
- Hysteretic
  - presliding
    (hysteretic
  - frictional
    (hysteretic

- Nonlinear friction

- Dynamic phenomena
  - Stribeck friction
    (describes transition from static to kinetic)

Technical Details: Fric

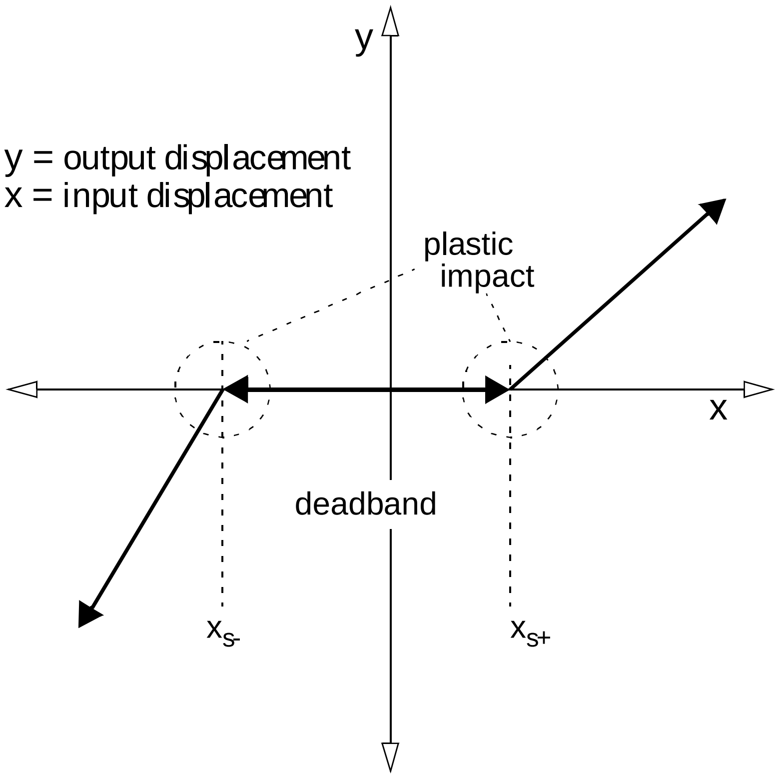


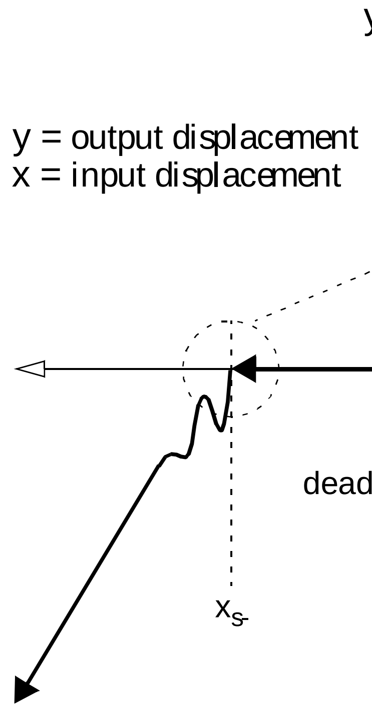


- Traditional model
  — discontinuity from static to kinetic

- Modern model
  — captures the dynam stiction and low v

Technical Details: Back

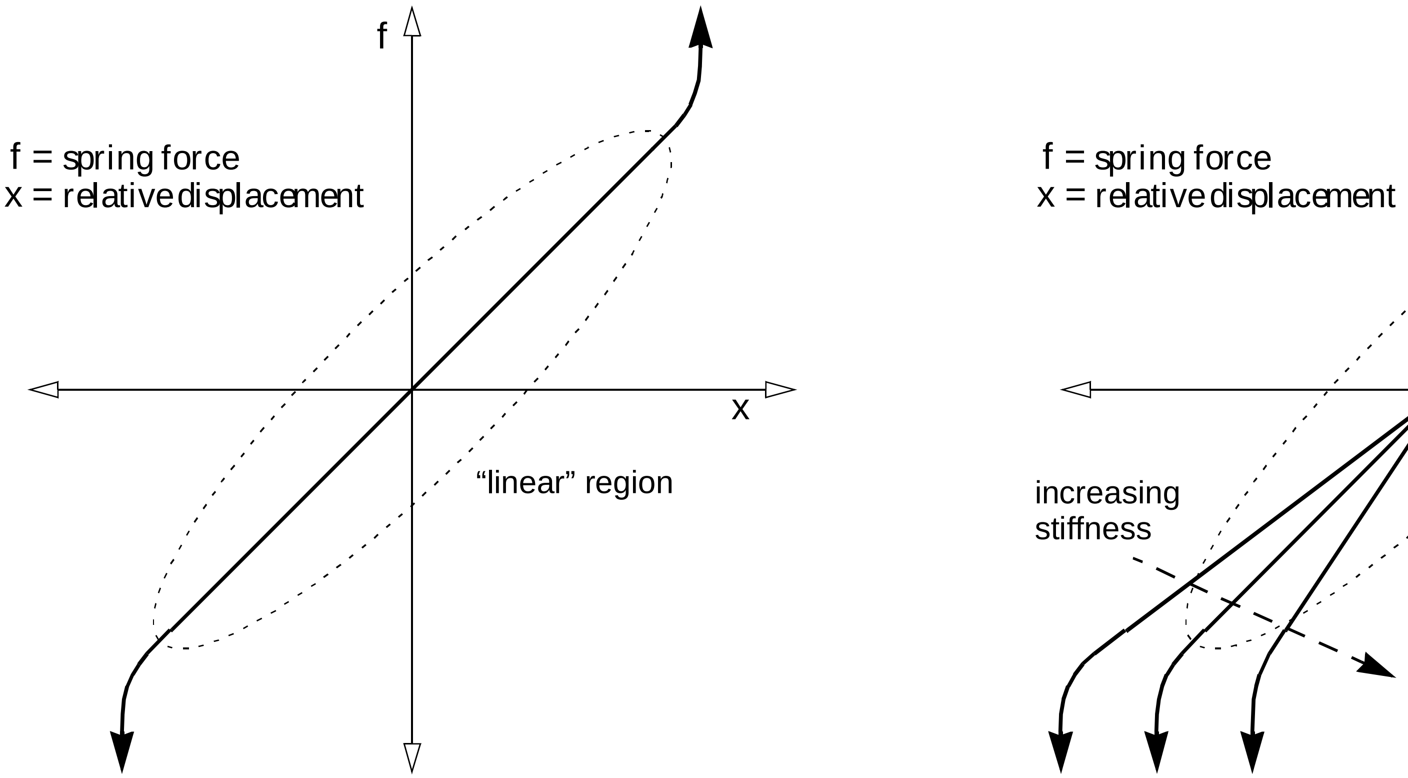




- Traditional model
  - — the backlash has no dynamic component

- Modern model (N
  - — impact-induced v included in the

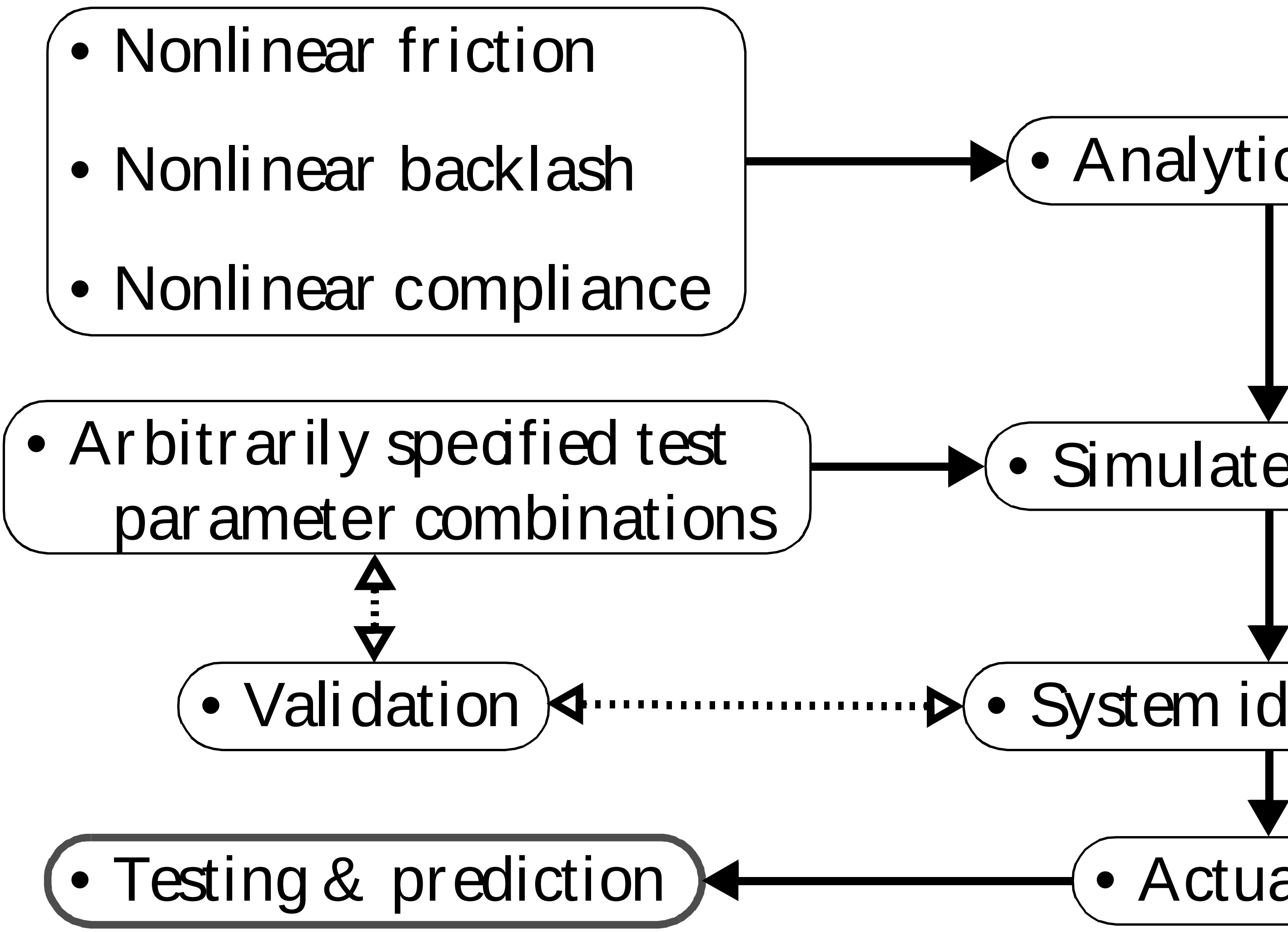
Technical Details: Comp



- Traditional model
  — spring force is unimodal and linear

- Modern model
  — multiple modes
  spring forces a

Technical Details: ID Pr



Technical Details: ID Me

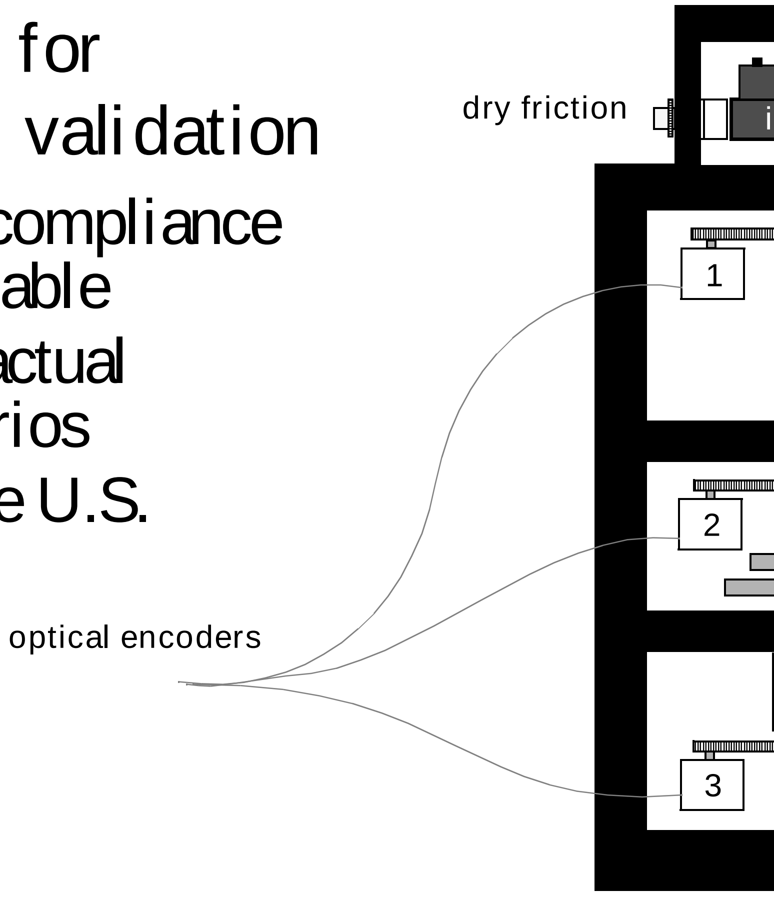
- Pros: Logarithmic decrement method
  - static, kinetic, and viscous friction
  - linear compliance
- Pros: Hilbert Transform
  - kinetic and viscous friction
  - unimodal nonlinear compliance
  - backlash with impact

- Cons
  - requ
  - piec
- Cons
  - requ
  - sim
    fun
    no

- Pros: Wavelet Transform
  - multimodal nonlinear compliance
  - cleaner data than Hilbert Transform

Results: Test Bed

- Unique test bed built for experimentation & validation
  - — friction, backlash & compliance are arbitrarily adjustable
  - — can mimick various actual machines and scenarios
  - — one of only two in the U.S.



Results: Objectives Ach

- Modeling
  - — analytical models of nonlinear subsystems develop
  - — analytical model of fully-coupled subsystems in si
- System ID
  - — traditional methods extended to piecewise linear sy
  - — nonlinear Hilbert method verified on friction
- Actual machine dynamics
  - — system ID techniques corroborate published param

Results: Friction ID Exa

- System withou
  - Coulomb fric
  - viscous fricti
  - frictional bia
  - compliance
- Excited via th
  harmonic os
  - free vibratior
    logarithmic
    Hilbert Tran
  - dual analyses
  - also provide

Results: Experimental

- Log decrement method
  — estimates compliance,
  Coulomb friction and bias
- Hilbert Transfor
  — estimates frictio
  also can estimat

Unique Contribution

- New dynamic backlash model
  - state-of-the-art backlash model augmented to includ
- New dynamic model & simulation of drive non
  - fully nonlinear, coupled equations-of-motion
  - simulation of arbitrary friction, backlash & complian
- New parametric harmonic oscillation ID
  - experimental method using P+D feedback to achieve vibration response in overdamped systems
  - machine resonance frequencies automatically eschew
  - method allows use of log decrement, Hilbert and wav out requiring a sine-sweeped forced harmonic oscill
  - produces estimates of inertia and mass-based system

Continuing Work

- Identification
  - — backlash
  - — backlash with compliance
  - — asymmetric (direction-dependent) nonlinearity
  - — periodic friction
  - — static and hysteretic friction
- Analysis
  - — extension to Wavelet Transform analysis
- Application
  - — automation of identification procedure

Future Work

- Application
  - — apply testbed results to an actual machine tool
  - — motorised workpiece table on drill press in laborat
- Extension
  - — on-line and adaptive system ID techniques
- Development
  - — feedforward control and adaptive control

Lab Demonstration

- Nonlinear system modeling and simulation
- Signal processing details
- Mechatronic implementation
- Friction identification
- Backlash identification
- Compliance identification
- Machine tool instrumentation approach