Tribomechadynamics
The Emergence of a New Field at the Confluence of Tribology, Contact Mechanics, and Structural Dynamics

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• What is Tribomechadynamics?
  – Fundamental relationship between Tribomechadynamics and interfacial mechanics

• Case study: the Brake-Reuß beam
  – Application of contact mechanics to structural dynamics design; parameter studies; role of wear

• Research in Tribomechadynamics
  – Surrogate System Hypothesis
  – Experimental insights
• What is friction?
  – The sliding resistance between two surfaces in contact with relative tangential motion
• Consider case of frictionless contact (e.g. lubrication):

Result: even in a lubricated joint, you still have frictional forces for high contact loads…
Structural Dynamics
- Vibration and nonlinear dynamics
- Reduced order modeling
- System level analysis (macroscale)
- Simple, pointwise contact models; usually heuristic in nature
- Typical experiments use shakers, impact hammers, accelerometers
- Typical models are dynamic, finite element or reduced order models
Tribomechadynamics Constituent Research Areas

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**Contact Mechanics**
- Elasticity and plasticity solutions
- Static stress analysis
- Focus on the contact patches (spans meso- and macroscale)
- Contact models usually are large, spatially distributed, and based on Coulomb.
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**Tribology**
- Wear
- Surface evolution over time
- Focus on micro- and nano-scale features
- Contact models usually are for asperity on asperity contact
- Typical experiments use tribometers or other wear rigs in addition to profilometers
- No such thing as typical models (tribology spans many disciplines…from solids to fluids to chemistry)
Goal of Tribomechadynamics

- Given an assembly,
  - Predict response during design stage
  - Predict performance degradation over time
  - Use models to optimize joint designs (weight/properties/wear/etc)
## Taxonomy of Issues – Multiscale Interface Dynamics!

<table>
<thead>
<tr>
<th>Scale</th>
<th>Description</th>
<th>Diagrams</th>
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<tbody>
<tr>
<td>Macroscale</td>
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<tr>
<td>Meso- and Microscale</td>
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<td>Nanoscale</td>
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How Do We Design Joints?

- Industry standards
  - Purely based on solid mechanics, how a load is carried, etc.
  - No consideration for dynamic effects
  - Indirect consideration for tribological issues (regarding wear)
- Research perspective
  - Academic communities, though inter-related, have not traditionally collaborated here.

[Diagram of a dovetail joint with radial oscillations and a flat pad approximation]

Where is wear?
Ramifications

• Dynamic designs are “the worst possible designs from a solid mechanics perspective.”

• Solid mechanics designs have no consideration for dynamic effects, resulting in massive over designs.

• Wear often addressed after a design is fabricated (not a priori)
Case Study: Benchmark System

- The Brake-Reußen beam is a structural dynamics benchmark adopted by approximately 20 institutions

- Multiple versions exist to assess the effects of interface design, and influence of the structure on joint properties
Dynamic Response

- Typical characterization: Ring Down Response -> Modal Filter -> Hilbert Transform -> Polynomial Fit -> Extraction of Amplitude Dependent Frequency and Damping
Case Study: Interface Designs

- Modified interfaces to investigate role of geometry on system properties
Case Study: Interface Design Dynamic Responses

- Lessons from solid mechanics led to a linearized dynamic system
- Linearized systems are much more conducive to design
- Ultimate goal: design tools…
Second set of interface modification experiments studied the effect of curvature.

- **Conformal**:
  - 50 – 50
  - 250 – 250
  - 1000 – 1000
  - 5000 – 5000

- **Non-conformal (convex)**:
  - 50 – 0
  - 250 – 0
  - 1000 – 0
  - 5000 – 0

- **Non-conformal (concave)**:
  - 0 – 50
  - 0 – 250
  - 0 – 1000
  - 0 – 5000

Baseline:
- 0 – 0
  (three slides back)
Case Study: Interface Curvature; What Is Linear?

- Perceived linearity depends on contact patch and excitation amplitude
Solid line: high amplitude excitation
Dashed line: low amplitude return
Case Study: Low Cycle Fretting

- Direct observation of wear where we expected it:
Tribomechadynamics in Action

Load Support

Time

Stiffness/Damping

Damage
Tribomechadynamics in Action

Measure the interface geometry

Experimental Validation

Next gen joint models
- Preserve local kinematics
- Parameters all physical

- Rough contact Iwan model
- 2 parameter friction model

Numerical Modeling

\[ \rho(\phi) = \frac{\mu \frac{p}{\phi T} A}{\phi T} = \frac{K_T}{\phi} \]
Research in Tribomechadynamics

• System-scale: how do we \textit{predict} the dynamic properties of a system?
  – Surrogate System Hypothesis
  – A Priori Metrics Hypothesis

• Multi-scale: how can we incorporate the effect of evolving surfaces into a system-level simulation to assess its effect on system dynamics?

• Multi-scale: investigation of the nonlinear transfer of energy between scales, aka “Mechanical Turbulence”

• Meso-/nano-scale: how can we \textit{predict} wear performance for an arbitrary joint?

• Numerical methods: need for efficient, nonlinear interface reduction methods

• Uncertainty quantification: need for methods to propagate uncertainties through models \textit{efficiently}

• Nonlinear system identification: need for methods to characterize mode coupling
Acknowledgements

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ND-CSI Summer Program 2018

- The Institute for Nonlinear Dynamics of Coupled Structures and Interfaces (NDCSI) is now accepting applications.
- Six week long research collaboration
- Hosted by Imperial College London, in London, UK
- July 4th to August 10th, 2018
- Directed by a three person steering committee: Matthew Brake (Rice University), Christoph Schwingshackl (Imperial College London), and Malte Krack (University of Stuttgart)
- Four projects for the 2018 Institute:
  - Evolution of Wear and Joint Behavior
  - Suitability of Asymptotic Numerical Method for Friction Damping
  - High Speed Camera DIC to Monitor Joint Behavior
  - Continuation Method for Bladed-Disk Vibration with Contact and Friction
- Email brake@rice.edu or c.schwingshackl@imperial.ac.uk for more information, or visit: http://brake.rice.edu/nd-csi
- Applications due March 2nd.
- Some travel support is available.