Parameterized Friction Modeling With Optimized User Constructs

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Our Team

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Many systems hold components in place through clamping.

Friction is notoriously difficult to model.

Determining required clamping often takes many cycles of destructive testing.
Compliant Friction Modeling

➢ Micro scale surface features change friction coefficients

➢ True surface area increases as compression increases

➢ Compliant materials deform and “fill” voids from surface features

➢ FEA required for simulation

[1]
Our Project

Model
➢ Build a 3D model in SolidWorks
➢ Mesh using CUBIT
➢ Simulate in SIERRA under different conditions

Build design advisor
➢ Import user conditions
➢ Determine successes and failures
➢ Find regions of success, failure and uncertainty

Test and verify
➢ Test at simulated points
➢ Test at high preloads based on prediction function
➢ Input test data into design advisor for comparison
Simulation Parameters

➢ Efficiency of simulations were paramount

➢ Pad deformation is critical to the validity of the simulations

➢ Hundreds of simulations required
  ➢ Sweep over geometries, pad materials, and compressions
  ➢ Automated through Python scripts
Simplified Geometry

➢ Model on right was used for bulk simulations
➢ Verified against the exact model for stress distribution
➢ Allowed for 3x timestep size
Simulation Steps

Apply compression
- Uniform force across the top plate
- Force increases with cycloidal ramp
- Time to settle

Apply shock
- 2ms Haversine pulse
- Allow it to dissipate

Output data
- Position data
- Acceleration data
- Element death
Simulation Workflow

Inputs
- APREPRO
- SIERRA
- CUBIT mesh

Workflow
- Execute job on cluster

Outputs
- Heartbeat file
- Paraview simulation
Simulation Results
Design Advisor
Design Advisor Simplified Overview

Inputs
- Simulated data
- User input data
- User fail criteria
- Requested output graphs

Data processing
- Import principal simulation data
- Determine maximal successes & minimal fails from failure criteria

Optional data processing
- Check additional requested graphs
- Import secondary simulation data
- Apply failure criteria

Outputs
- Plot best fit success & failure functions
- Plot failure criteria against displacement
- Save all figures to host computer
Design Advisor Outputs

- Cork Max final displacement: 0.001(m), Max oscillation: 0.01(m)
- $r^2$ Min Fail = 0.9634
- $r^2$ Max Success = 0.8941

- Silicon70 qin Displacement over time preload (lbs): 2160, G-force: 2100
Displacement Over Time

Cork qin Displacement over time preload (lbs): 2160, G-force: 2400

Silicon70 qin Displacement over time preload (lbs): 2160, G-force: 2100

Silicon70 qin Displacement over time preload (lbs): 2160, G-force: 1800

Silicon70 qin Displacement over time preload (lbs): 2520, G-force: 2400
Design Advisor

cork Max final displacement: 0.001(m), Max oscillation: 0.01(m)
silicon70 Max final displacement: 0.001(m), Max oscillation: 0.01(m)
silicon30 Max final displacement: 0.001(m), Max oscillation: 0.01(m)
Verification & Testing
Test Methodology

1. Center pads in carriage
2. Bolt to preset preload using torque wrench
3. Bolt to drop table
4. Add padding to control shock duration
5. Add/Remove padding based on internal shock experienced
6. Take initial position of part at two points
7. Replace initial carriage with new carriage
   - Un-torque initial carriage
   - Recenter part
   - Re-torque initial carriage
8. Adjust height of drop given initial shock
Data Collection

- High speed video
  - Displacement over time
  - Pad deformation and slip
- Accelerometers
  - Part kinematics
  - Time dependent, quantitative data
- Digital Calipers
  - Precise final displacement
Test Results

Cork qin max final displacement: 1 (mm), max oscillation: 10 (mm)

Silicon70 qin max final displacement: 1 (mm), max oscillation: 10 (mm)

Silicon30 qin max final displacement: 1 (mm), max oscillation: 10 (mm)
Limitations & Future Research
Limitations

**Simulation Limitations**
- More rotation in plates than observed in testing
- $\mu_s$ changes based on compression
- Deterministic simulation of stochastic process

**Advisor Limitations**
- Maximum success point dependent on range swept
- Oscillations do not always terminate in time
- Cannot predict specific displacements

**Test Limitations**
- Pulsed shock duration is inconsistent
- Bolts lose compression after shock
- Shock amplitude is inconsistent and infeasible to predict a priori
Areas to explore & expand

Vibrations and modal effects

Temperature

Pad fatigue

Exotic pad materials

Test geometry

Controlled failure
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References


Friction Modeling With Rigid Materials

- Dependent on micro and nano scale surface features

- True surface area changes friction coefficient

- Compression independent

- FEA often required for simulation

[2]
Simulation Acceleration VS Test Acceleration

sil30qin8th Acceleration over time preload (lbs): 1440.000000, G-force: 1500

Test 50 Acceleration over time
Design Considerations & Central Questions

➢ Will a shock displace a compressed part?
➢ What are the failure conditions?
➢ How much compression is there?
➢ How large is the shock?
➢ How long is the shock?
➢ What is the pad material?
➢ What is the pad geometry?