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Rate-state friction in an FOTAS coated nanotractor

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Acknowledgements

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Erin Flater – University of Wisconsin - Madison

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Rate state formulation

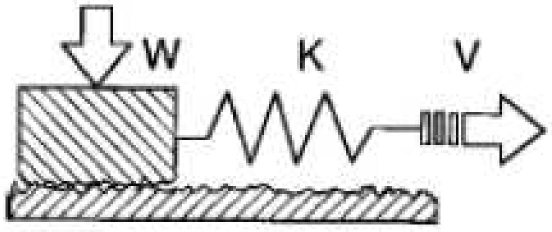
Empirical extension to Amontons' laws

Contact aging causing increase in friction over time for static system

For moving system, friction decreases with velocity as contacts have less time to age

Important over length scales ranging from earth quakes to MEMS (present work)

Typical experimental setup



Berthoud et. al, PRB 59 (1999) 313

Interface ages (strengthens) at rest, while it rejuvenates (weakens) when sliding sets in.

Caroli et. al, J. Phys IV France 12 (2002).

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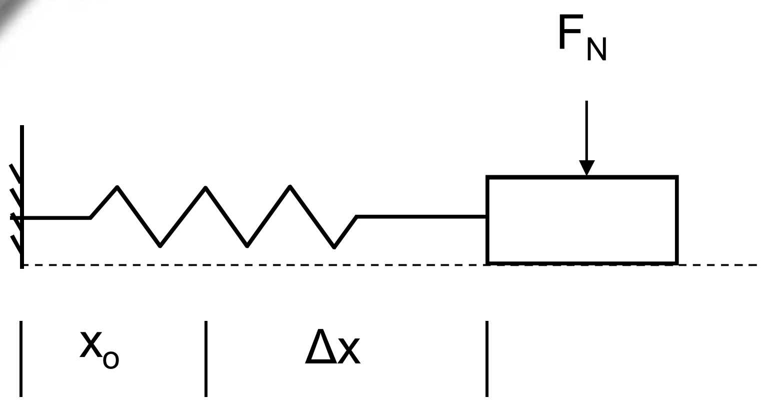
Measurement / nanotractor

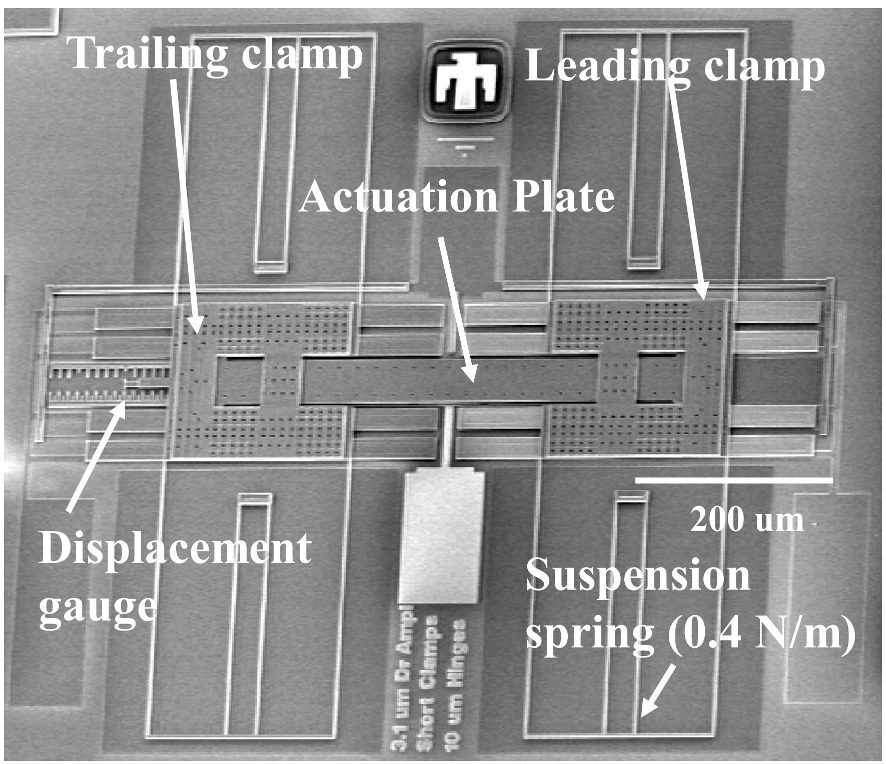


Normal force provided by electrostatics

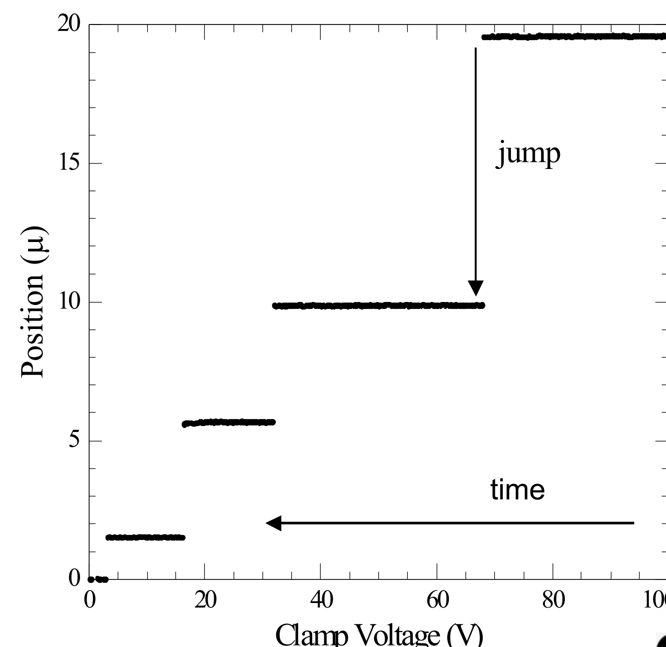
Start at initial position Δx

Ramp down voltage (normal force) and record position

By looking at jumps can determine coefficient of static friction



Raw Data



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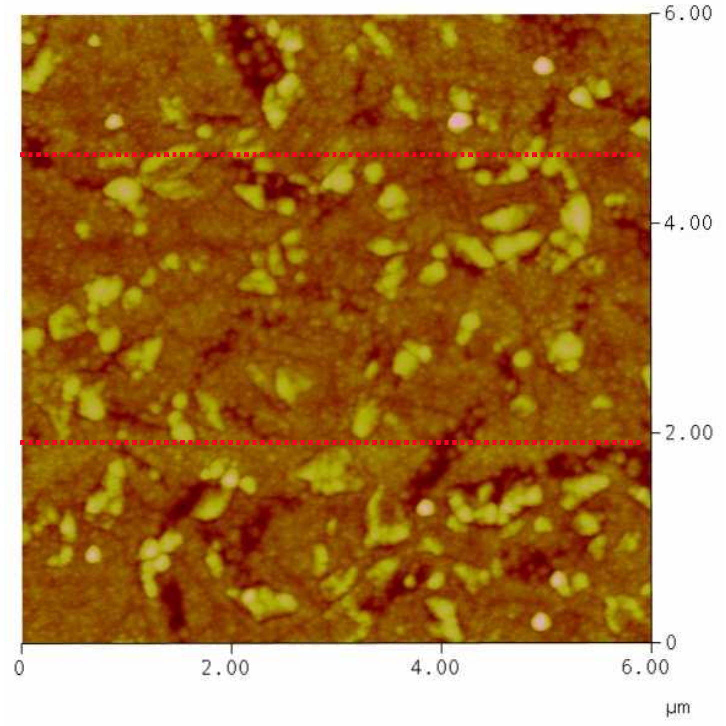
Surface

Polysilicon with vapor deposited FOTAS coating

Rms roughness ~ 3.6 nm

SUMMiT V™ process



FOTAS (tridecafluoro-1,1,2,2-tetrahydrodecyltris(dimethylamino)silane)

vapor deposition

8 carbon chain

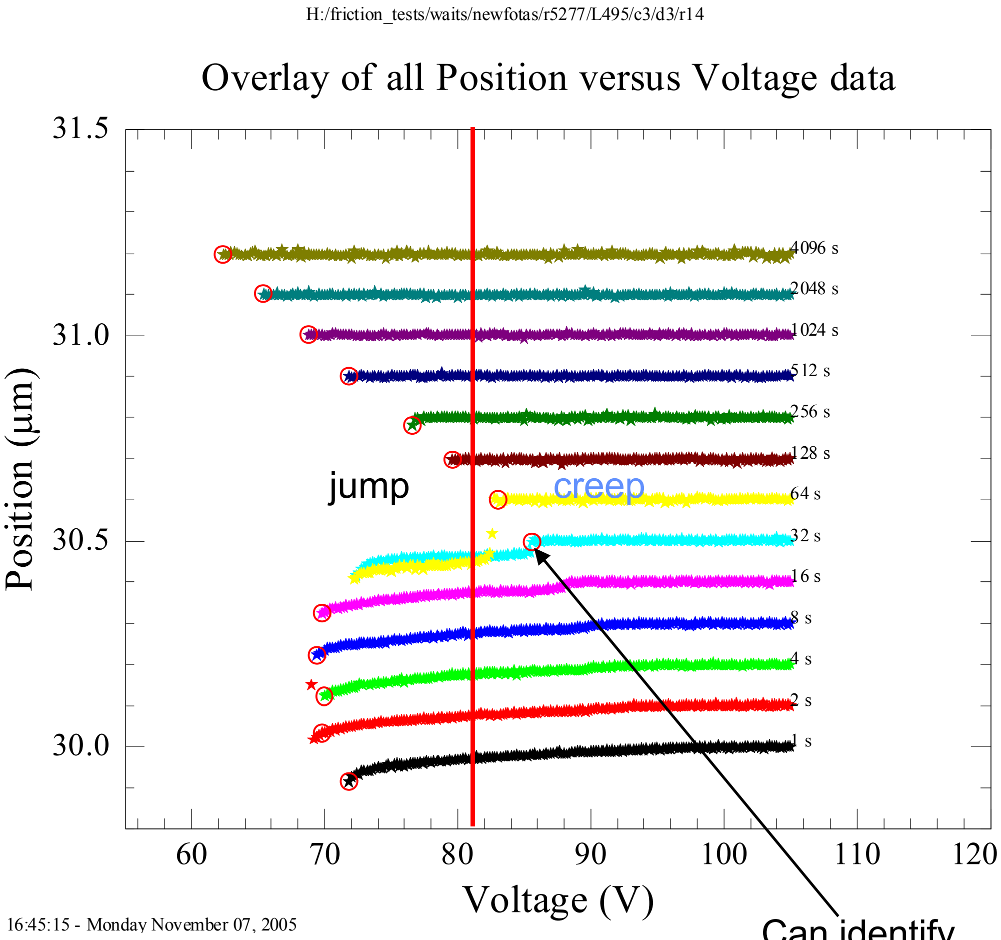
van der Waals forces not strong enough to self assemble (tangled)

contact angle ~ 110° (hydrophobic)

Vary hold time

Hold at initial position for varying amounts of time and then ramp down voltage in .2 volt steps

Identify jumps when position changes greatly on release and creep as small position change on release

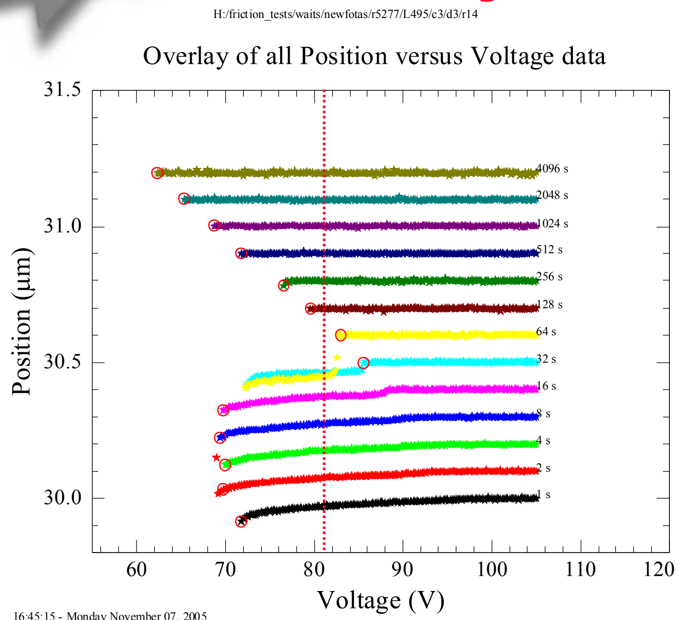


Can identify friction events without jumps

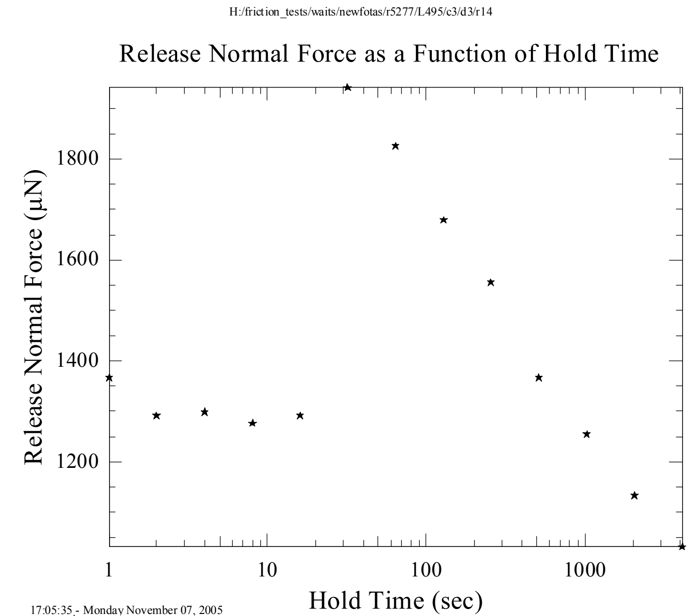
Observe dependence of jump position on hold time

Notice transition between jumps and creep

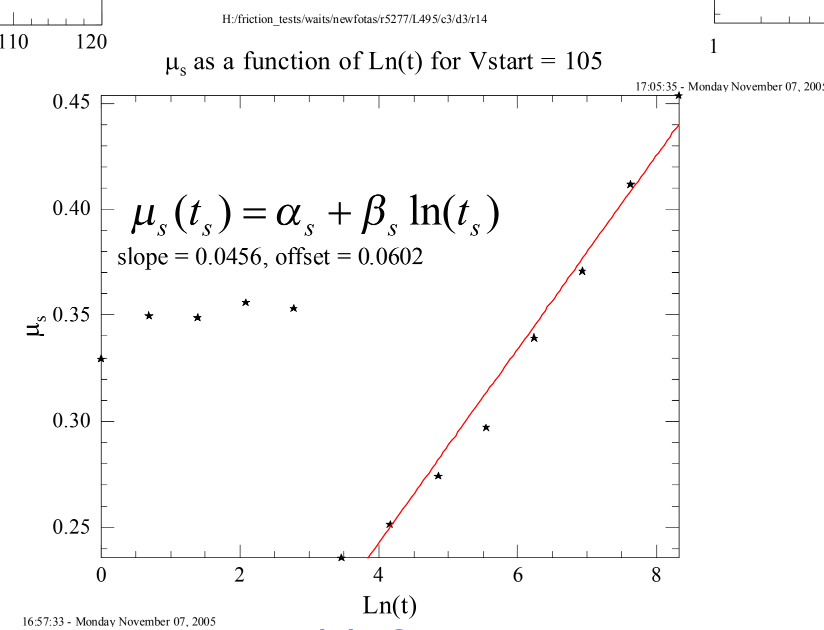
Analysis of variable hold time data



pick off friction event points and plot as a function of hold time

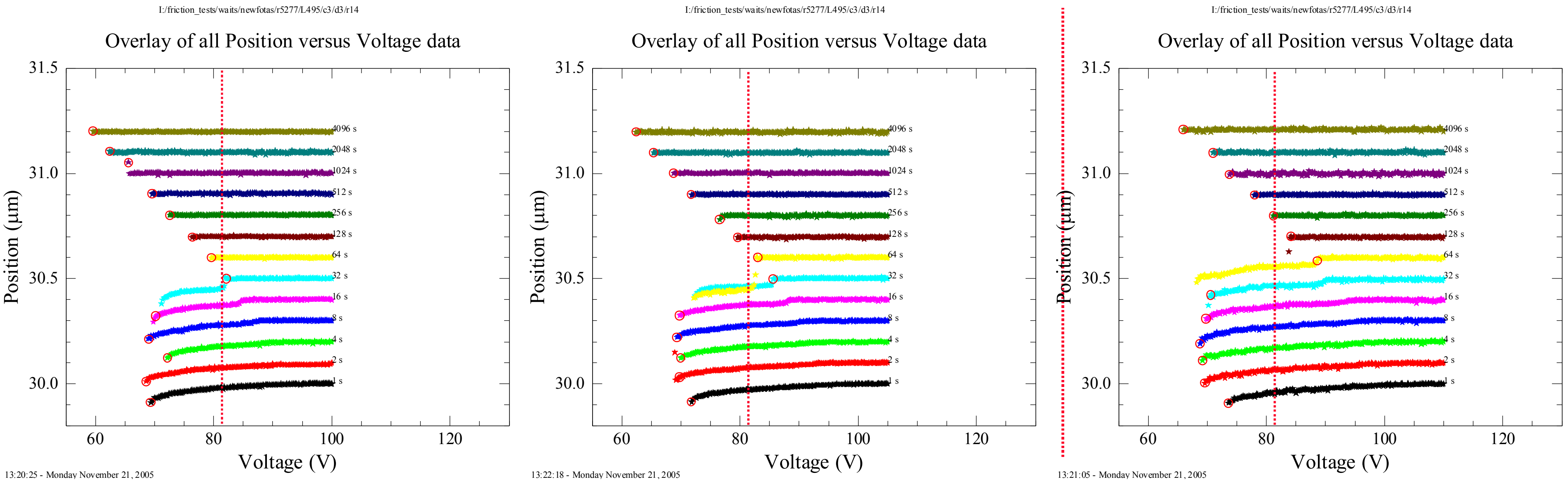


Contacts age with time leading to an increase in friction



Can fit as classic rate-state ln(t) friction dependence

Vary initial normal force



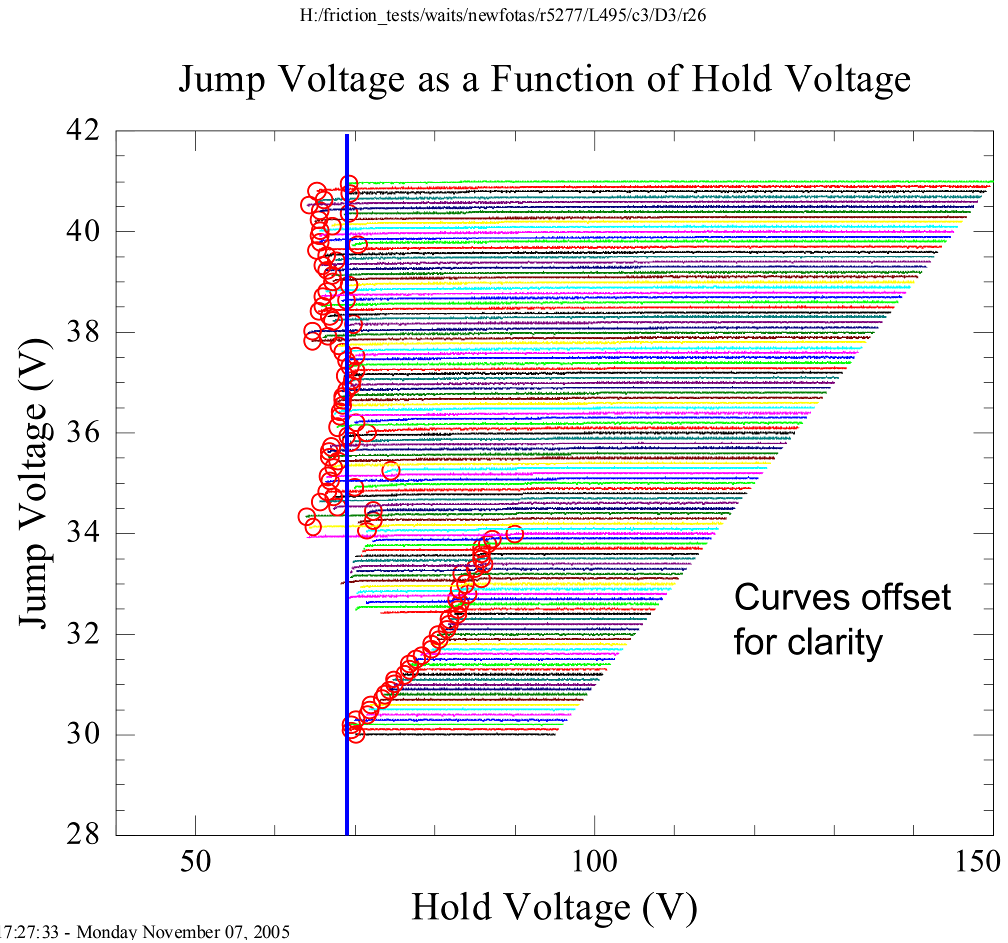
Curves shift to the right as we increase hold voltage

Also, more curves exhibit creep as we increase hold voltage. Red dashed line seems to indicate seperation between creep and jumps

Systematic variation of holding force

For a fixed initial position, vary initial voltage and record position as a function of ramped down voltage

Once friction event has occurred, memory is lost, and jumps occur for same value of voltage (blue line)



Position of first jump increases as the vstart voltage increases (i.e. larger normal force).

Holding with larger normal force -> lower friction force

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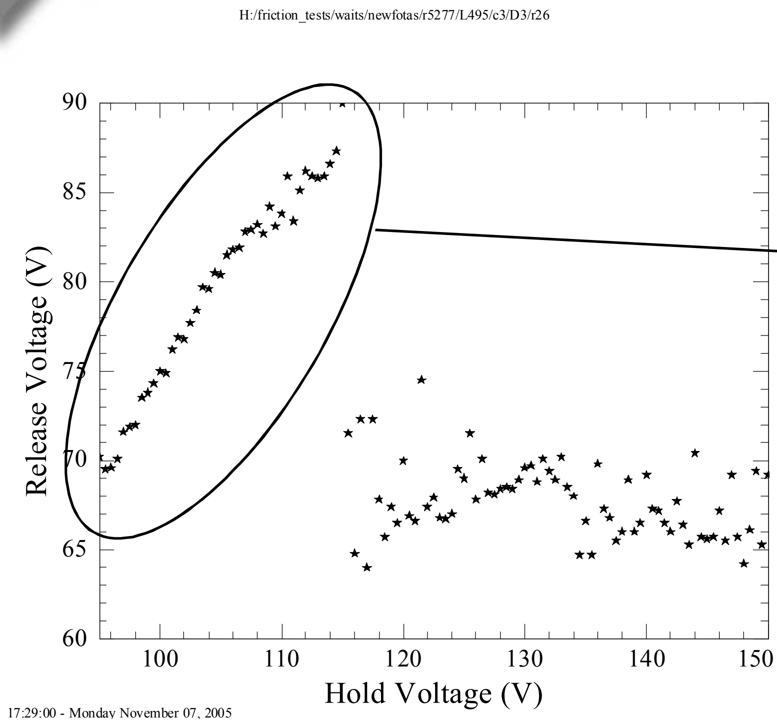
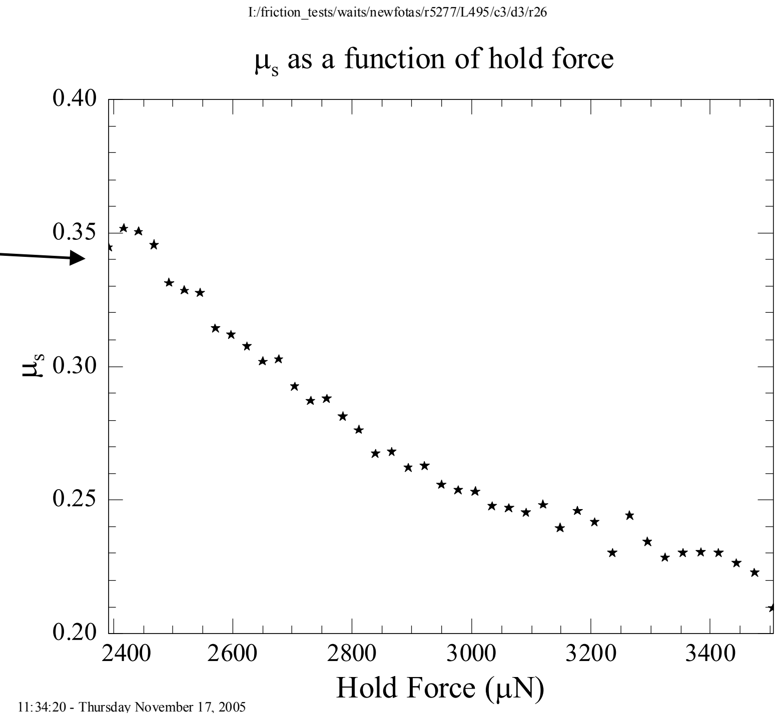
Analysis of variable holding force



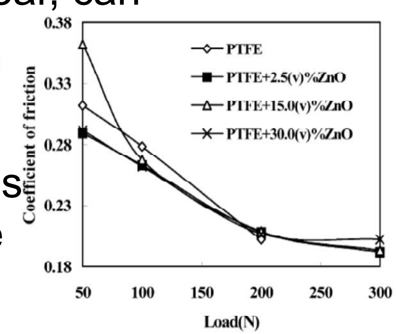


Can plot friction event as a function of hold voltage. When first event is clear, can plot u_s as a function of hold force

The friction and wear characteristics of nanometer ZnO filled polytetrafluoroethylene

Fei Li*, Ke-ao Hu, Jian-lin Li, Bin-yuan Zhao

State Key Laboratory of Composite Materials of Metal Matrix, Shanghai Jiaotong University, Box A9905091, Huashan Road 1954, Shanghai 200030, PR China



Reduction of friction with normal force has been observed in polymer systems as visco-elastic effect, but function dependence does not fit what we observe

High pressure expected to reduce ordering of mono-layer leading to decrease in coef of static friction

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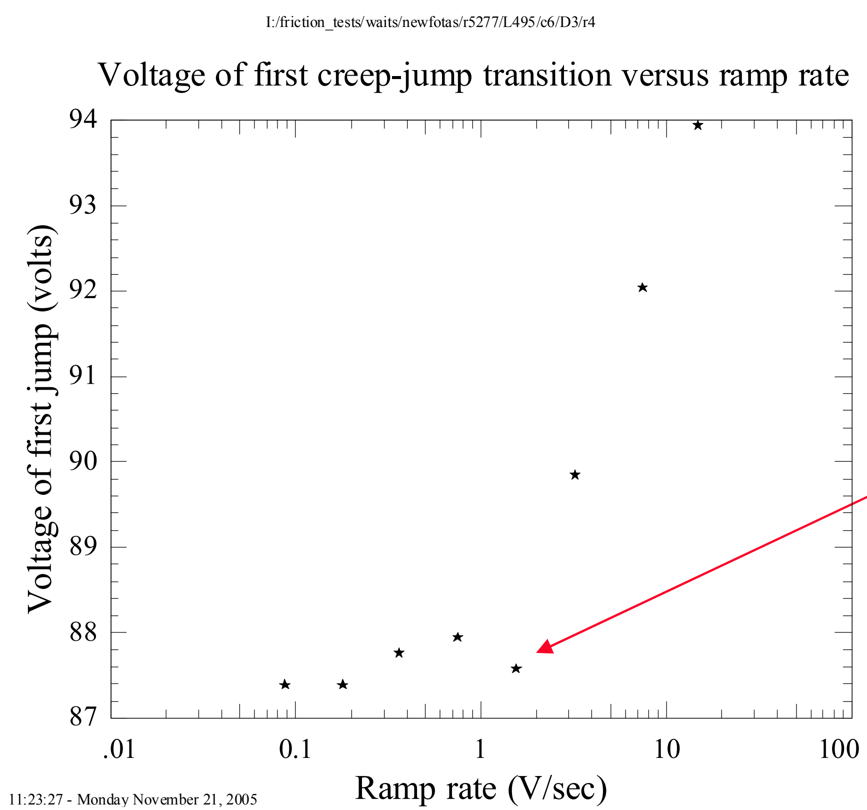
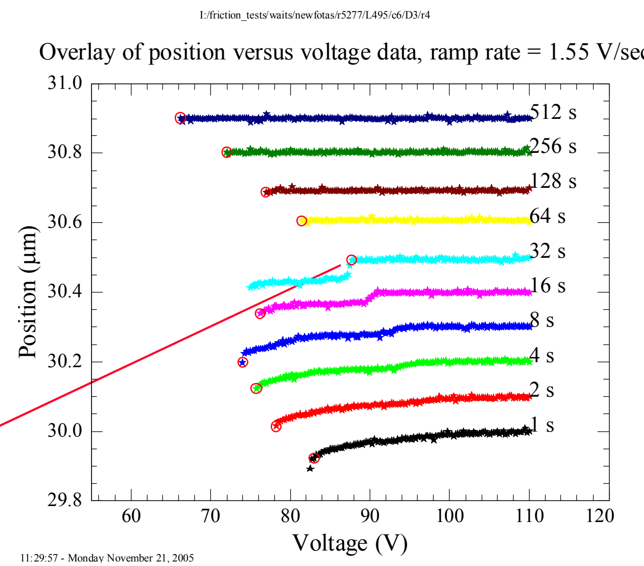
Vary ramp rate

We can vary ramp rate by changing the step size

Data reduction



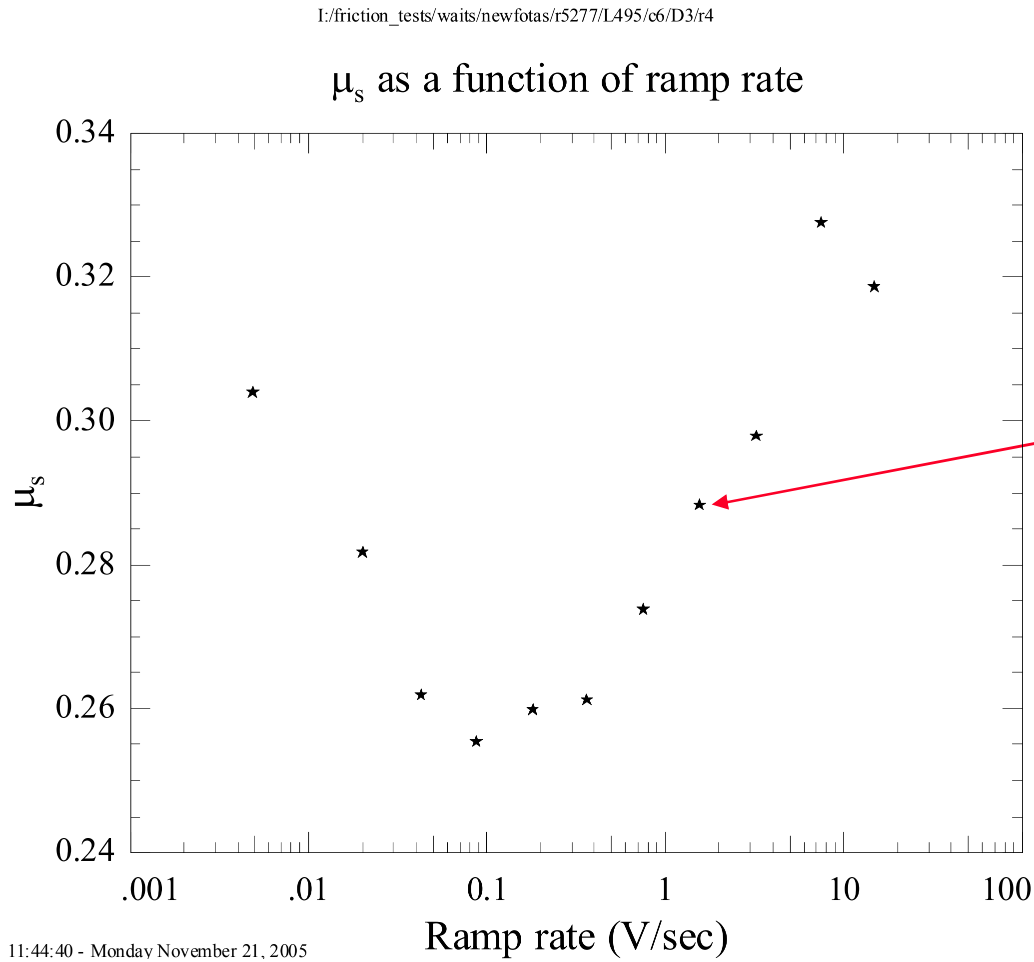


Pick off voltage for last creep

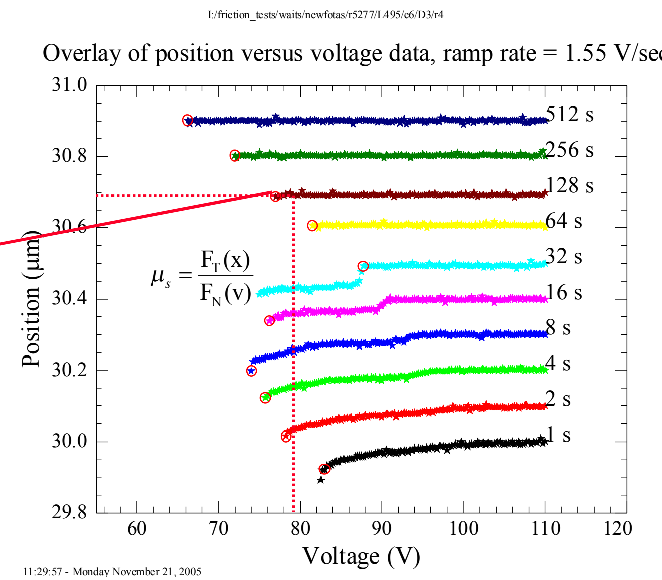
Repeat for various step sizes

Step size does not change position of first clean jump

Friction changes with stepsize



Measure friction for 128 second hold time

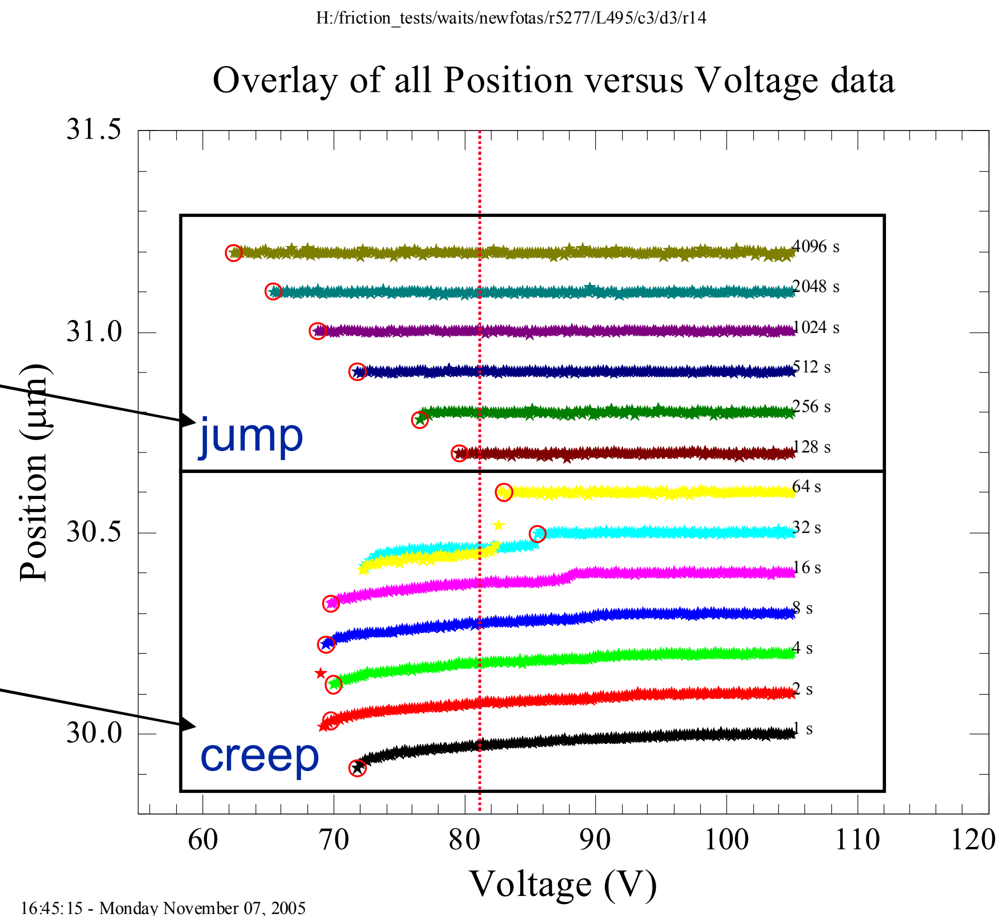


As ramp down time increases, more time for contacts to separate, effectively reducing the effect of the hold time. For slow enough ramp downs, this effect saturates and contacts will begin to experience appreciable aging, leading to an increases of static friction

Jumps versus creeps

Friction events at lower voltages feel less friction after start to move (no memory of initially high friction)

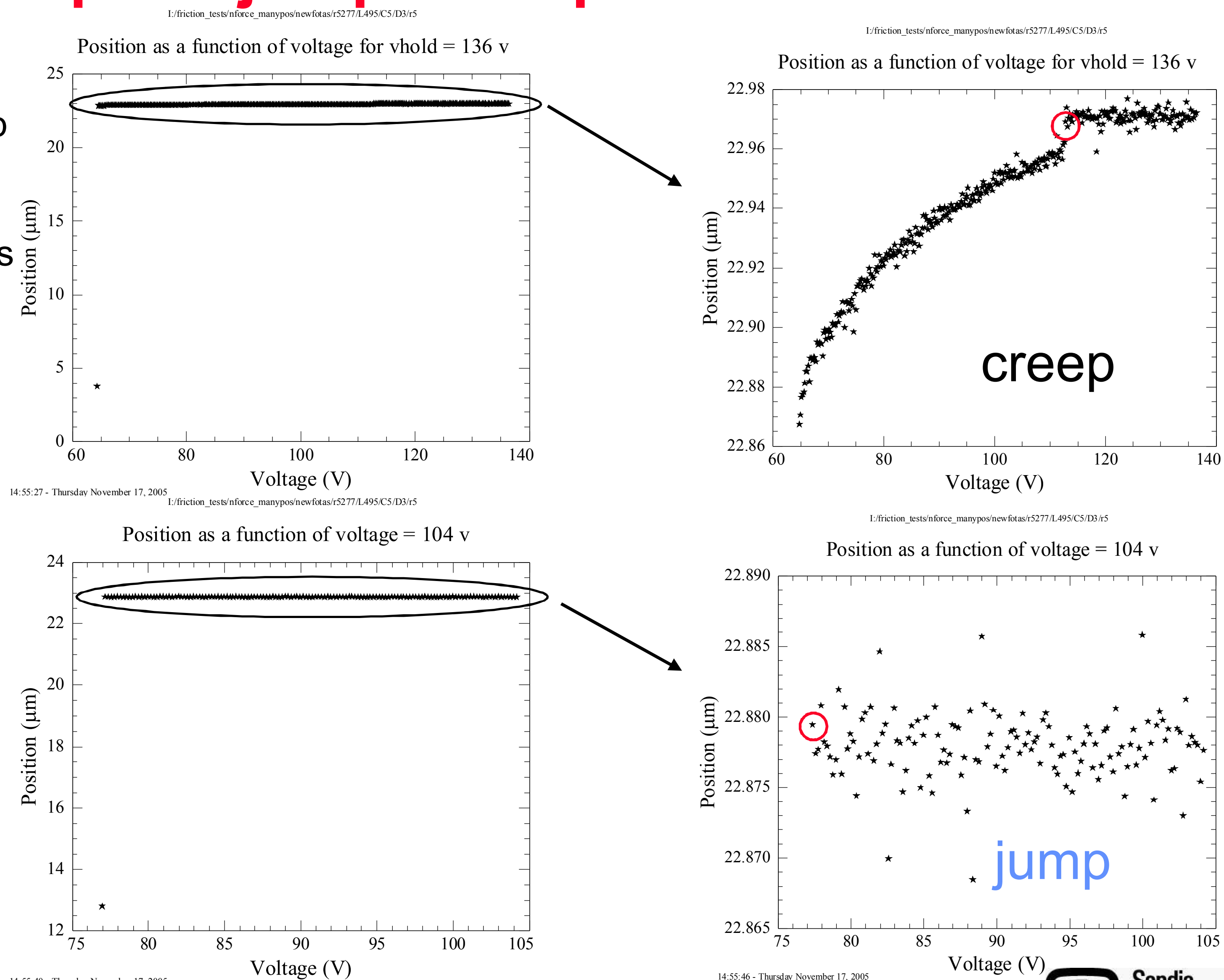
Friction events at higher voltages feel more friction after start to move (no memory of initially low friction)



Explore jump / creep transition

Perform voltage ramp down (.2 v/step) for a variety of normal forces to move across jump to creep boundary.

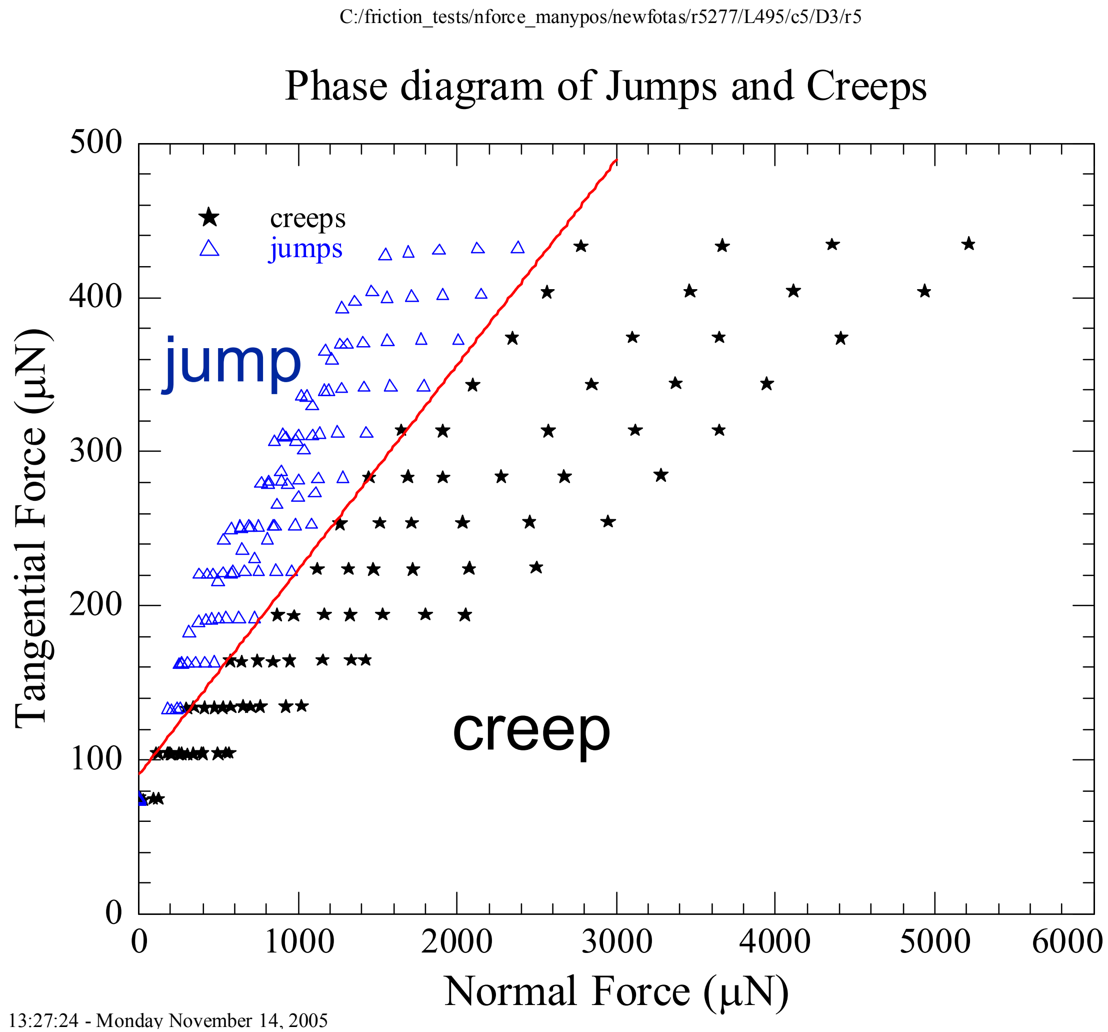
Repeat for many positions to measure boundary as a function of position



For this position, transition is between 75 and 112 volts

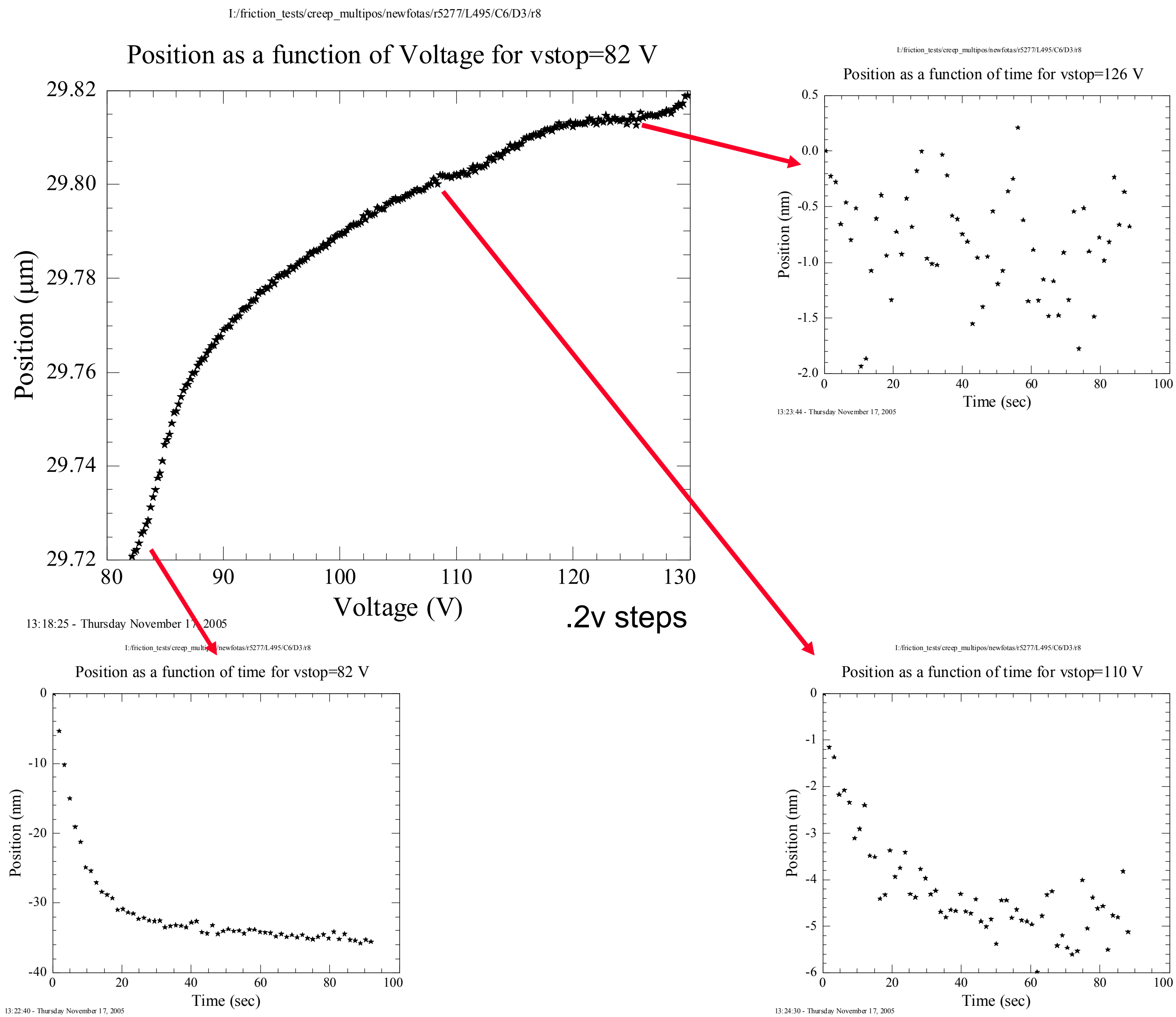
Phase diagram of jumps and creeps

For each tangential force (position) plot type of event as a function of normal force (voltage)

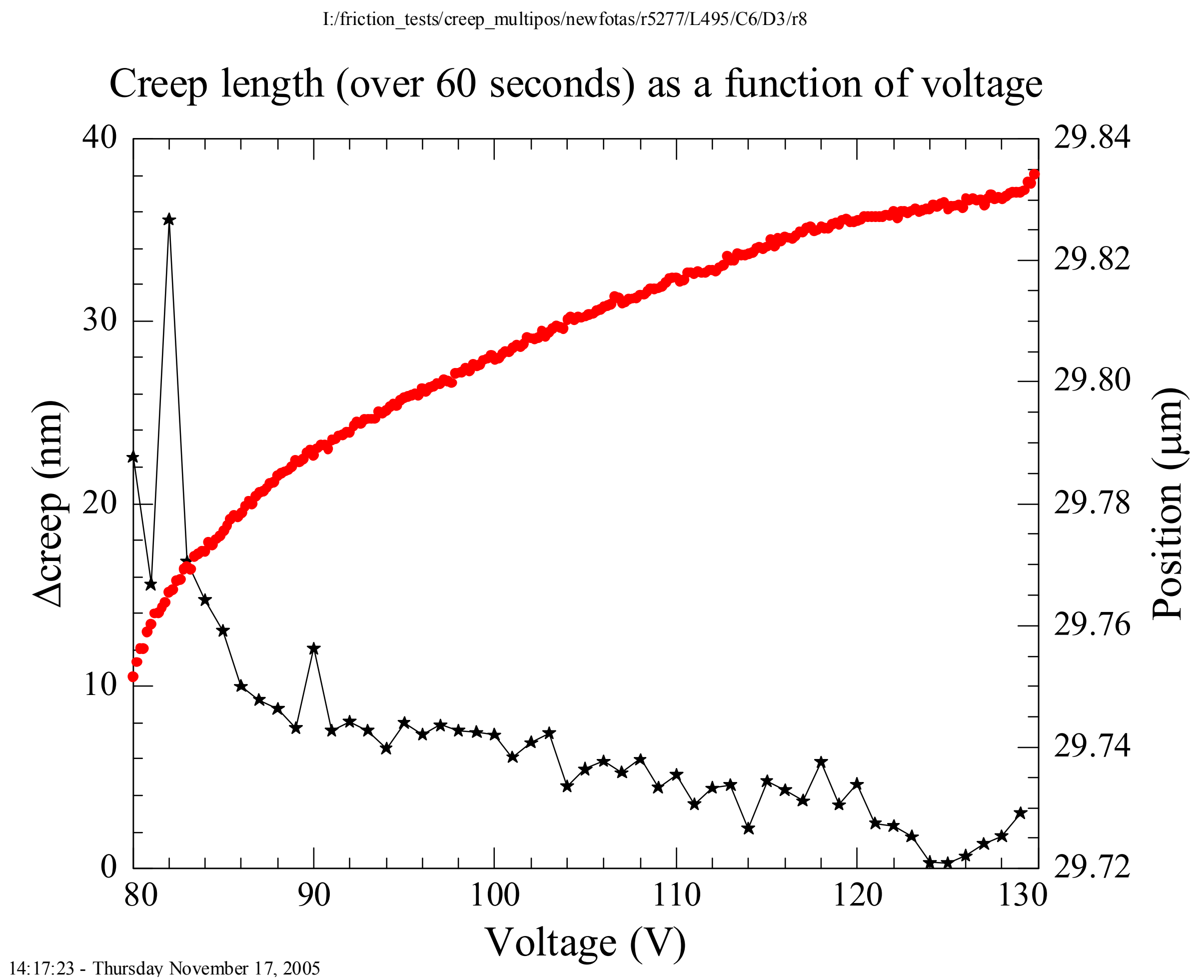


Roughly linear boundary line between jump and creep

Time dependence of in creep regime



Creep length as a function of voltage



Creep length grows near jump. Repetitive measurement, so not exactly matched

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Summary and conclusions

Contact aging

static friction increases with time

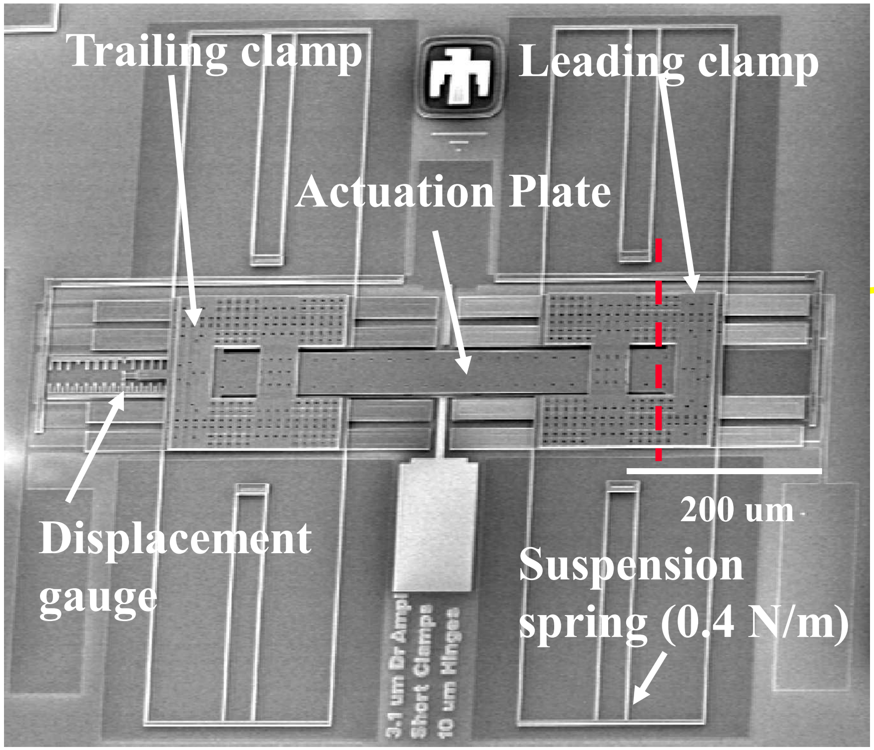
static friction varies with rate of normal force ramp down

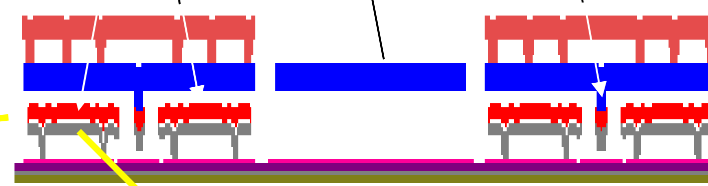
Static friction reduced with increase in initial loading force

Bifurcation between jump and creep behavior as function of tangential divided by normal force

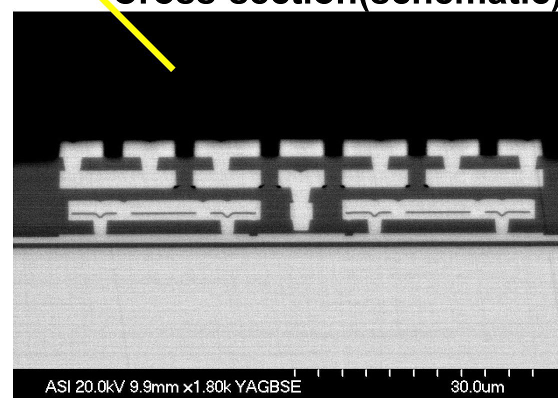
Time dependent creep increases before a jump occurs in the creep regime

The Nanotractor Device





Cross-section(schematic)



SEM of Friction Clamp

High-performance surface-micromachined inchworm actuator, de Boer, MP; Luck, DL; Ashurst, WR; Maboudian, R; Corwin, AD; Walraven, JA; Redmond, JM: Journal of Microelectromechanical Systems; Feb. 2004; vol.13, no.1, p.63-74

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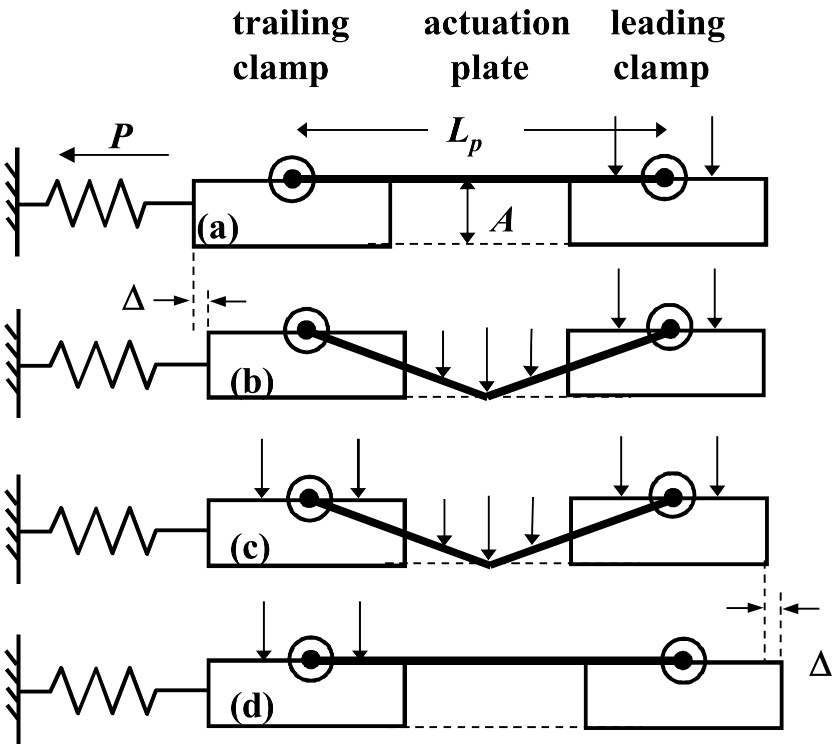
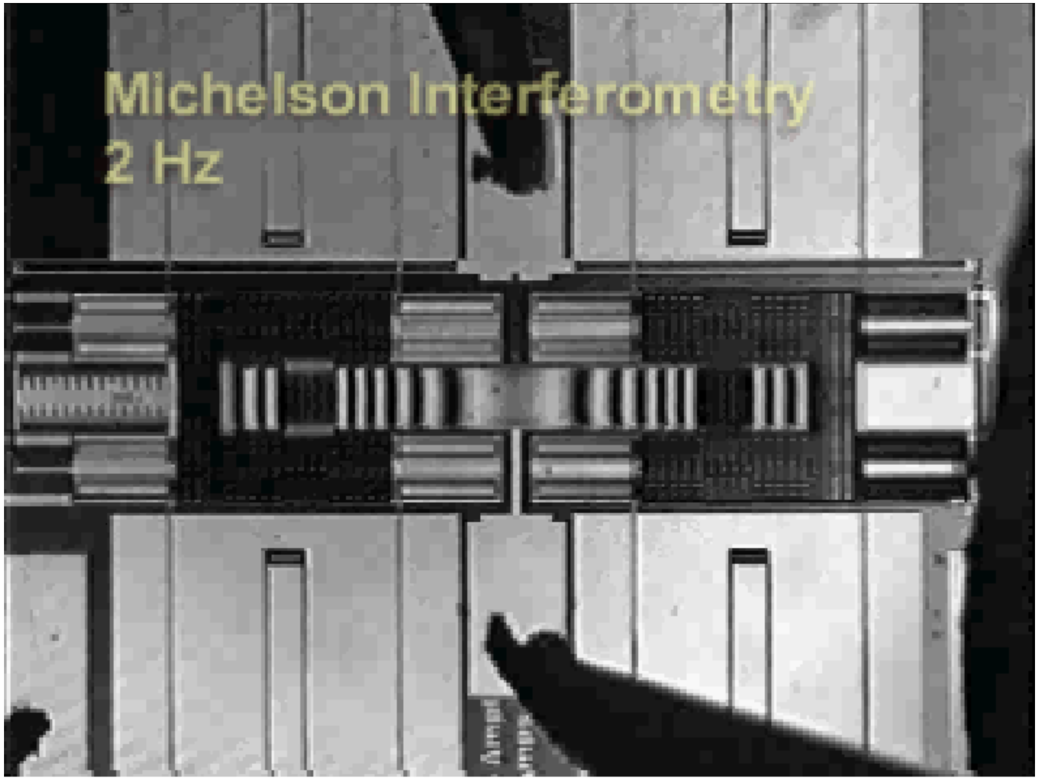
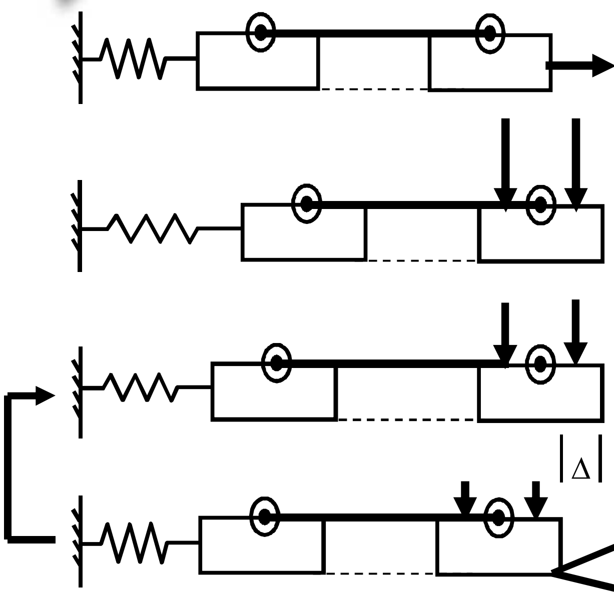
Driving the Nanotractor





(a) Clamp RHS
(b) Pull down driver beam
(c) Clamp LHS
(d) Relax RHS & driver beam

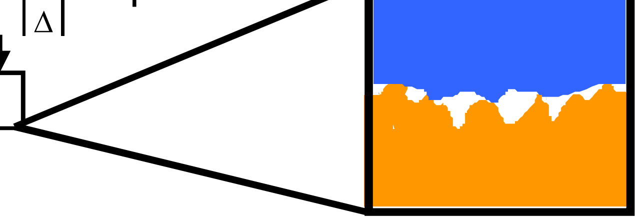
Static friction measurement



Walk out nanotractor against load cell

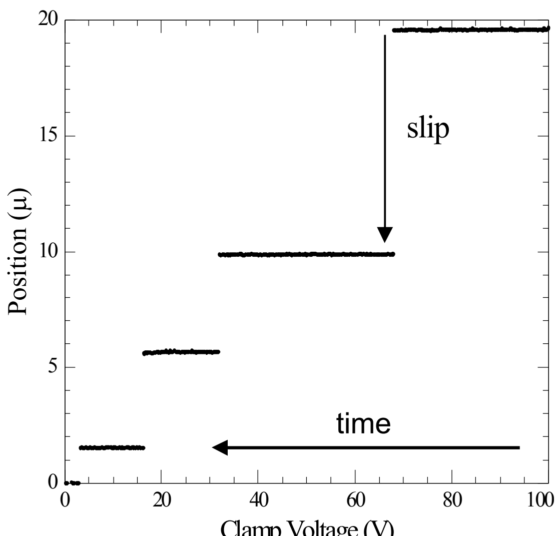
Apply large normal force (voltage)

Step down normal force (voltage) and record position



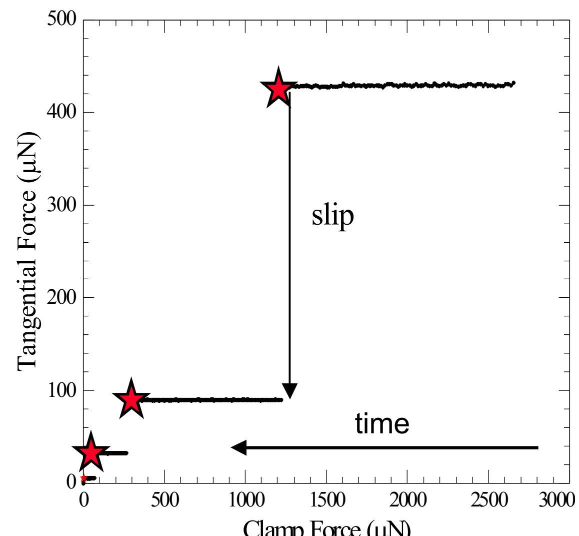
Contacting Asperities

Raw Data



Convert clamp voltage to clamp force and position to tangential force

Force Data



Identify equilibrium points right before jumps where

$$F_{Tan}=\mu_s F_N$$

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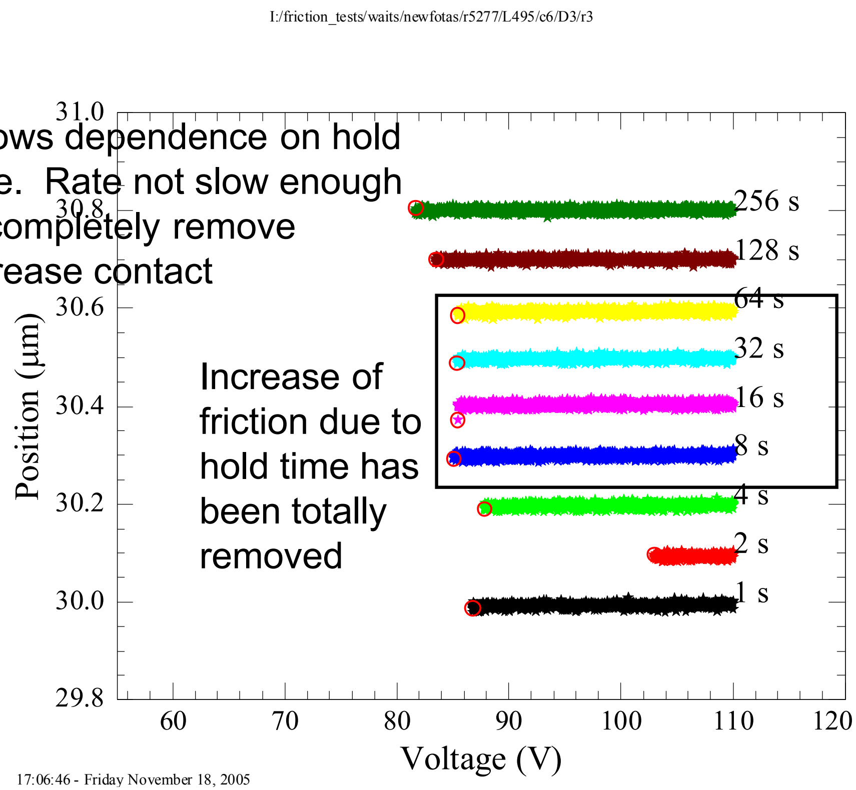
Shows dependence on hold time. Rate not slow enough to completely remove increase contact



Increase of friction due to hold time has been totally removed