Stabilizing stick-slip friction

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- stochasticity in the period between consecutive slip events
- irregularity in the size of the stress drops
What is the origin of this stochasticity?

- A diversity of surface contacts
- Nonlinearity of interactions between the slider and the surface
The model

Parameters:

$N$ – a number of rigid blocks,

$N_s$ – a number of contacts between the block and track,

$K_d$ – an elasticity of the driving spring,

$K$ – a slider elasticity,

$k_s$ – an elasticity of the contact,

$f_{si}$ – rupture forces which takes random values from a Gaussian distribution
A broad distribution of stick times is retained even when all contacts are identical.
Force traces for different numbers of blocks

- $N=8$
- $N=40$
- $N=50$
- $N=70$
\[ \Delta x_j = x_j - x_j^0 = \Delta x_1 \exp[-\sqrt{K_s/K_{\text{int}}(j-1)}] \]

**Stochasticity**: the nonuniformly stressed region involves more than one block, i.e.

\[ N \gg \sqrt{K_{\text{int}}/K_s} \]
Is it possible to control the stochasticity?

$$V_d = V_0 - \frac{2\pi}{T} \Delta \sin(2\pi t / T),$$
Control of Friction via Normal Oscillations


Anisoara Socoliuć, Enrico Gnecco, Sabine Maier, Oliver Pfeiffer, Alexis Baratoff, Roland Bennewitz, Ernst Meyer

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SFA Experiments
Effect of lateral vibrations


Shear velocity oscillations on stick-slip behavior on macroscale


No control

\[ F_L \]

Control

\[ F_L \]
Even relatively small perturbations can cause the interval between successive stick-slip events to phase-lock to the perturbation frequency.

\[ 0.002 < \frac{\Delta F_s}{F_s^m} < 0.05 \]
Phase locking: for frequencies much higher than the typical stick-slip frequency. The stick time adapts itself to the value of $T$, such that $\tau = nT$

$$\phi = 2\pi \Delta t / T$$

![Graph showing stick-slip behavior and phase locking](image)

![Phase locking and stick time adaptation](image)
Slip time relative to the forcing: temporal shift, $\Delta t$, from the closest peak of the force modulation.

\[ \phi = \frac{2\pi \Delta t}{T} \]

*Experiment* vs. *Theory*

\[ \eta = 2\pi \Delta / T V_0 \]

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Minimal possible value of the phase: the loading force associated with this phase is higher than the preceding maximum of $F_L$ in the loading curve.

\[ F_L = K_d[V_0t + \Delta \cos(2\pi t/T)] \]

\[ \phi_{\min} + \eta \cos(\phi_{\min}) = \Phi_{\max} + \eta \cos(\Phi_{\max}) \]

Controlling parameter

\[ \eta = \frac{2\pi\Delta}{TV_0} \]

• For values $\eta < 1$ the loading force changes monotonically with time and harmonic oscillations do not influence the stick-slip pattern.

• For $\eta >> 1$ we have the following asymptotic behavior of the phase:

\[ \phi_{\min} \approx -2\left(\pi / \eta\right)^{1/2} \]
(i) \( \eta \) is indeed a relevant parameter that controls a frictional response to harmonic perturbations.

(ii) There exists a minimum value of \( \eta \sim 1 \), below which no phase-locking is observed;

(iii) When control is applied a well-defined "backbone" exists, below which the onset of stick-slip motion will (nearly) never occur;

(iv) This backbone is described by the power law form: \( \phi \propto \eta^{1/2} \).

The data for stick-slip events are strongly clustered above this curve.
Conclusions

- Small oscillatory perturbations *synchronize* the periods between consecutive slip events.

- A *model* explains the experimental observations and elucidates the mechanism for phase locking.

- We have identified one of the *relevant dimensionless parameter* and shown how this functionally affects the locking phase.

- The main effect of perturbations on the detachment dynamics is the *elimination of slow fronts* which correspond to a *critical state*.