Reversibility and force behavior for cyclic shear of a granular material

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Introduction
We experimentally investigate the diffusion and contact forces in a two-dimensional granular system, an array of disks, exposed to oscillatory, linear shear. By comparison, slow viscous fluid flow is governed by time-reversible evolution equations. This reversibility breaks down for even quite dilute suspensions, as was recently shown[1]. The breakdown is abrupt and occurs at finite strain amplitude, as evidenced by a marked increase in particle diffusivity. We seek an understanding of the properties of this reversibility-irreversibility for granular systems. We study the reversibility of particle motion as a function of the volume fraction of disks and the shear amplitude. We find anomalous spatial and rotational diffusion and a sudden increase of the diffusivity around a particular volume fraction. Our data suggests that the reversibility transition observed by Pine et al can also be observed in dry granular media.

2D granular system
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Diffusion & reversible-irreversible transition
- Mean-squared Displacement: Sub-diffusive
- Mean-squared Rotation: Super-diffusive
- Diffusivity significantly increases around this region -- Reversibility-irreversibility transition!
- But NO forces visible in the packings at the same region

Cyclic shear
- 100-500 Shear Cycles
- Sheared (red) phases: transient behavior
- Force evolution of unsheared (blue) and sheared (red) phases: transient behavior
- On increasing φ and γ, we observe:
  - Increase of force value
  - Growing timescale of force dynamics
- in systems below jamming point, where one would expect only unjammed states to exist [2].
  - Shear-Jamming!

Force behavior: shear-jamming
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References: