Summary

We are examining a granular (sub-)monolayer subjected to horizontal vibrations in gravity. Depending on the excitation parameters \( A \) and \( \omega \) one can find three different dynamical states:

1. a 2d gas-like state.
2. a 2d condensed (often crystalline) state.
3. a 3d granular gas.

Here we consider only the transition 2 \( \leftrightarrow \) 3.

For fixed frequency and slowly varying amplitude of the oscillation, we observe an abrupt change of the system's dynamical state, where the system expands to the vertical dimension. This transition leaves its fingerprint in several measurable quantities, such as energy dissipation rate, sound emission characteristics and a gap size which quantifies the sloshing motion of the granulate. The well defined hysteresis of the transition can be understood by considering the energy of the collective motion of the particles relative to the container. Both transition forward and backwards occur at critical energies.

Measurement methods

We are collecting information about the system's behavior using 3 different methods:

- **Camera:**
  Observing the system via a high speed camera in front of the box. Analyzing the maximum free space to the wall, i.e. gap size \( l_g \).

- **Strain gauge:**
  Measuring the force \( F(t) \) needed to drive the system via a strain gauge between the box and the linear gear. Calculating the energy dissipation rate \( \eta \)

- **Piezo sensor:**
  Recording the sound emission via a piezo sensor attached to the side wall of the box. Calculating a quotient \( \lambda \) of the power spectrum \( P \)

Model

Energy equipartition:

\[
\frac{1}{2} m v^2 = m g d
\]

The velocity corresponding to the energy needed to lift a particle by its diameter equates to:

\[
v = 0.28 \text{ m/s.}
\]

If 24 particles (one row) are pushing the last particle this velocity is reduced to:

\[
v = 0.06 \text{ m/s.}
\]

The collision time \( t_c \) of the granulate with the wall is given by:

\[
\omega t_c = \sin(\omega t_c) + \frac{t_g}{A}
\]

Expanding for \( t_c \) the velocity between wall and granulate equates to:

\[
v = A \omega \left( 1 - \cos \left( \frac{6t_g}{A} \right) \right)
\]

which results in \( v = 0.066 \text{ m/s} \) for \( A_{\text{sub}} = 17 \text{ mm} \) and \( l_g = 0.8 \text{ mm} \) (experimental values).

After the first particle left the first layer, the gap size is increased rapidly and the full layer breaks up.

Lower boundary for the solid state \( A_{\text{sub}} \):

Maximum relative velocity is \( 2.4 \omega \), which results in \( A_{\text{sub}} > \sqrt{\frac{2}{3}} = 0.74 \text{ mm} \) (experiment: \( A_{\text{sub}} = 9 \text{ mm} \))

Acknowledgment

We acknowledge funding by Deutsche Forschungsgemeinschaft (DFG) through the Cluster of Excellence „Engineering of Advanced Materials (EAM)” and the Collaborative Research Center SFB814.

Results

For monodisperse granulate we use 4 mm steel spheres in a polycarbonate box of dimension \( L_x, L_y, \) and \( L_z \). The angular frequency \( \omega \) is fixed at 18.85 s \(^{-1}\). The power of the excitation is adjusted by the driving amplitude \( A \).

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**References**

M. Heckel, A. Sack, J. E. Kollmer, and T. Pöschel, Dynamical characteristics of horizontal vibrated granular matter, in preparation (2014)