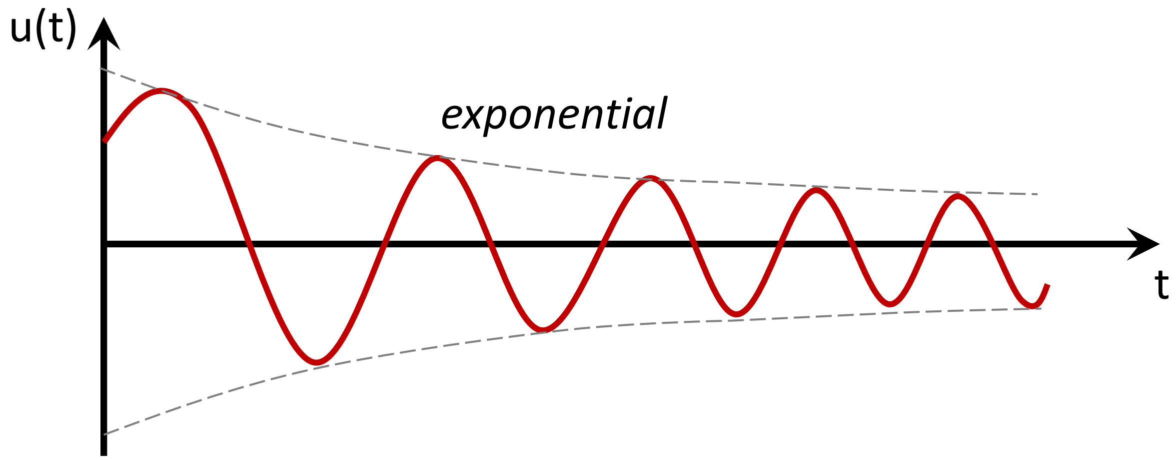
Damping models

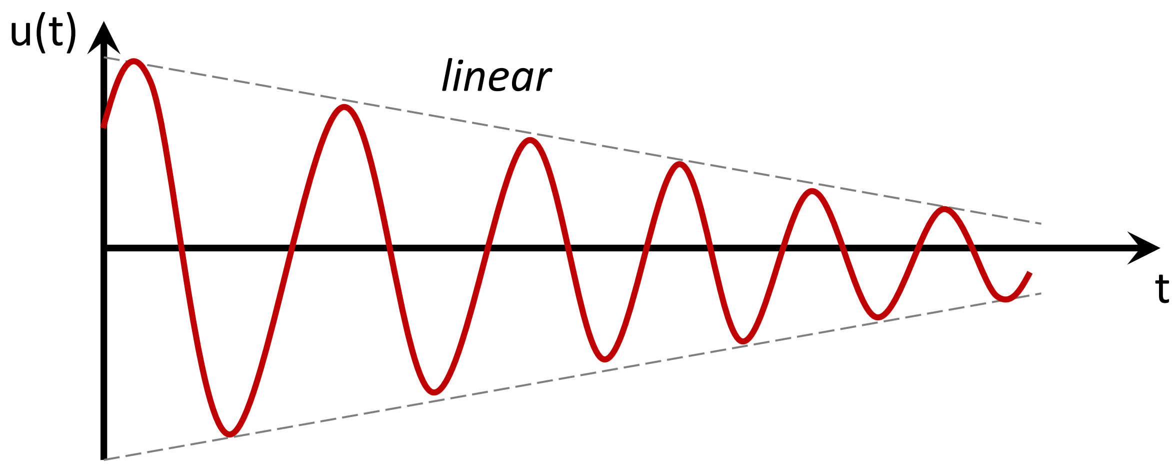
***viscous* damping**

- results from slow moving structures in fluids and gases, e.g.
  - friction bearings
  - hydraulic dampers
  - shock absorbers, ...
- damping force is *proportional* to velocity



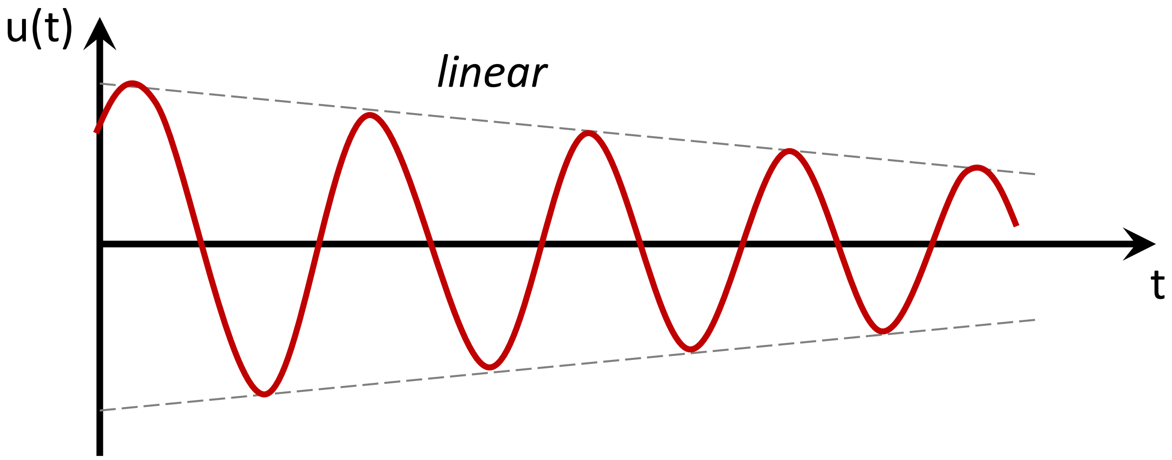
Coulomb damping

- results from friction on a dry surface, depending on
  - contact pressure
  - friction coefficient
- damping behavior is *constant*
- typical examples are bolt & rivet connections



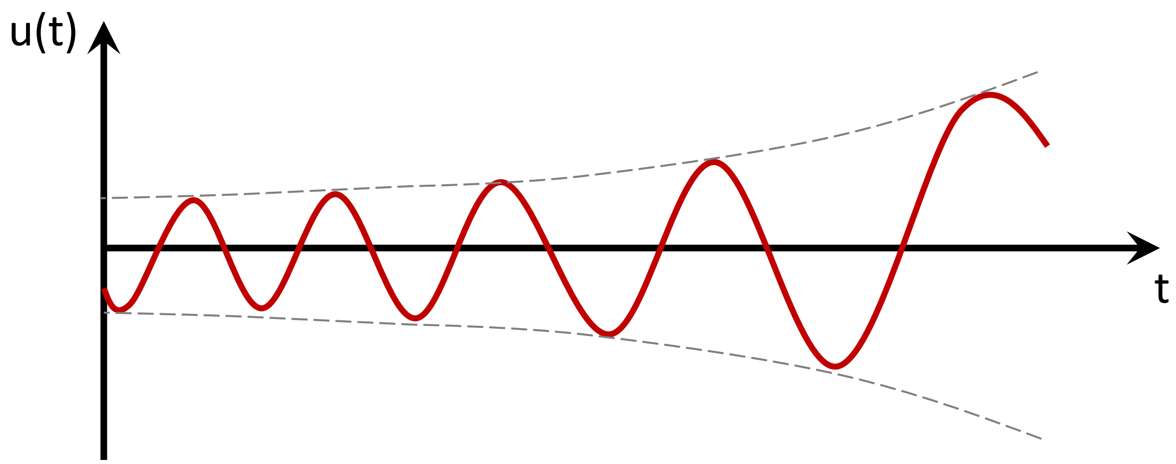
hysteresis damping

- results from internal friction of material (*structure damping*)
- damping forces are functions of displacements **u** and strains **ε**
- often measured experimentally from the hysteresis of a load-displacement diagram using harmonic excitation
- damping force (absolute value of) is proportional to elastic forces



negative **damping**

- appears at e.g. flutter of aircrafts
- energy input instead of energy dissipation
- energy input from streaming fluids
- results in excitation of the structure



properties

- in general several damping effects are present in *real structures*
- damping models are often highly complex
- simplification is necessary with regard to the solution process of the governing damped equations of motion
- equivalent viscous damping models often replace complex damping models (equivalent = same energy dissipation)

- damping matrix can be derived analogue to consistent mass matrix

$$\mathbf{C} = \int_{\Omega} \mu \, \mathbf{N} \, \mathbf{N}^T \, d\Omega$$

properties

- damping matrix $\mathbf{C} = \int_\Omega \mu \, \mathbf{N} \, \mathbf{N}^T \, d\Omega$
- symmetric, often sparse
- without relation to $\mathbf{K}$ and $\mathbf{M}$ → **non-proportional damping**
  - decoupling of equations of motion difficult/not possible

- alternative approach → **proportional damping**
  - e.g. Rayleigh damping

$$\mathbf{C} = \alpha \, \mathbf{K} + \beta \, \mathbf{M}$$

  - pro: eigenvectors of undamped problem diagonalize $\mathbf{C}$
  - con: use of only two free parameters α,β

properties

- alternative approach → **proportional damping**
  - e.g. Rayleigh damping

$$\mathbf{C} \;=\; \alpha\,\mathbf{K} + \beta\,\mathbf{M}$$

  - often choice of α, β depending on the *damping ratio* ξ_i

$$c_i \;=\; \alpha\,\omega_i^2 + \beta \;=\; 2\,\xi_i\,\omega_i$$

  - ξ_i represents a percentage of critical damping,
    e.g. 2-5% for metallic materials → 0.02 $\leq \xi_i \leq$ 0.05