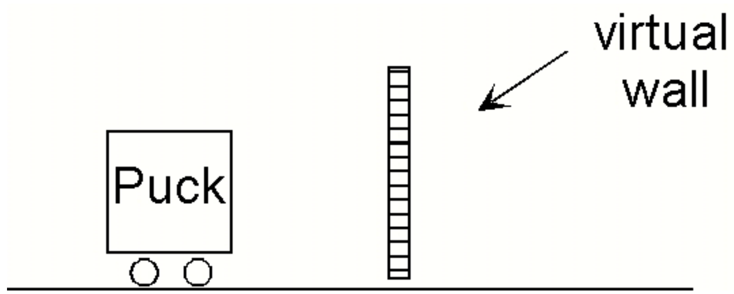
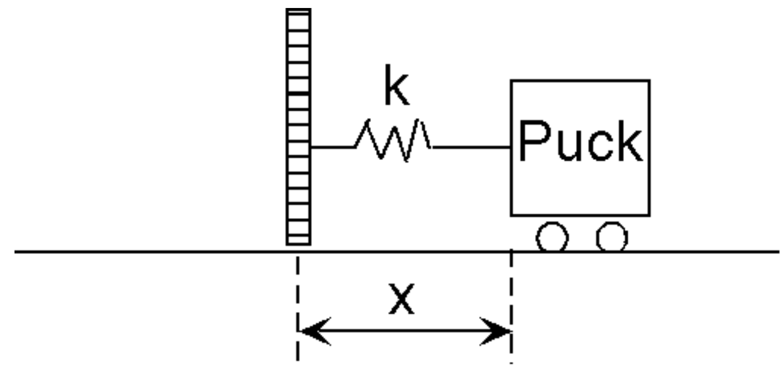
Virtual Wall





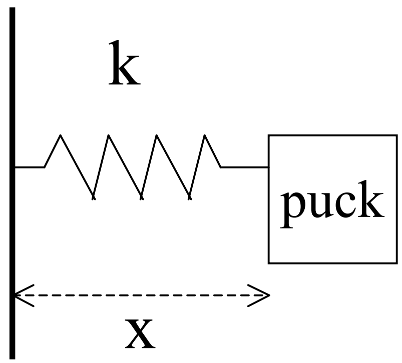
- Software loop
  - read position from encoder
  - compute force F = 0 or F = kx
  - set PWM duty cycle
- Rotary motion
  - degrees ⇔ encoder count
  - torque ⇔ PWM duty cycle
  - 1 degree into wall ⇔ XX N-mm torque

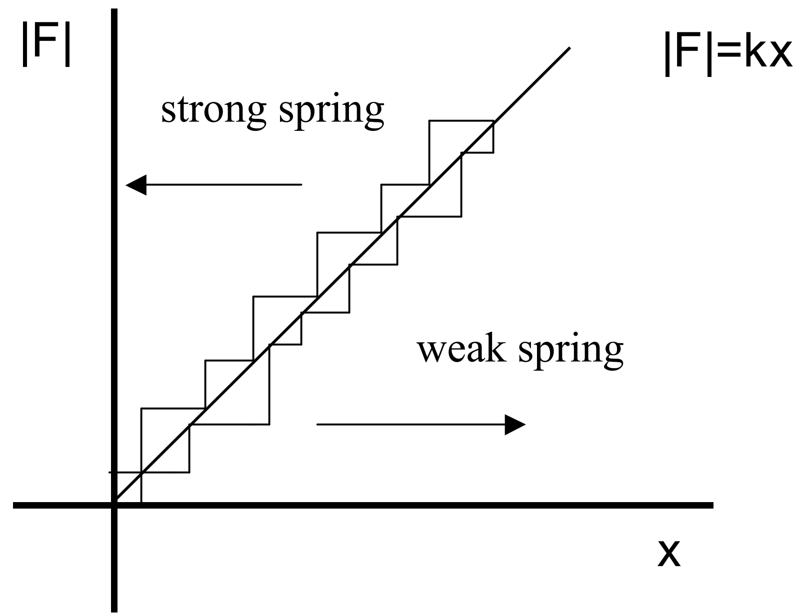
- Wall chatter
  - large k required to make stiff wall
  - limit cycle can result due to sampling, computation delay, quantization, synchronization

Wall Chatter

- A “stiff” virtual wall requires large k.
- Large k causes the wall to chatter.
- Limit cycle caused by interaction between human control and computer control at the wall boundary.
- Complete study requires a model of the human.
- Researchers assume the human is passive, and attempt to build passive walls.

"Energy Leak"





digital implementation of virtual spring
⇒ ZOH contributes ½ sample delay
⇒ spring adds energy

$$W = \int F dx$$

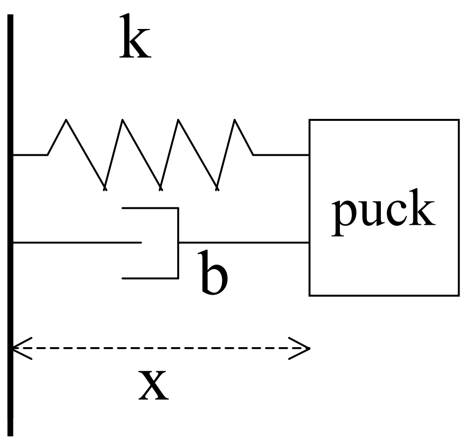
Half Step Prediction

- Predict puck position one step ahead and use spring law

$$F(n) = -k\left(x(n) + \hat{x}(n+1)\right)/\,2$$

$$\hat{x}(n+1) \approx x(n) + \dot{x}(n)T$$

$$F(n) = -k\left(x(n) + \tfrac{T}{2}\,\dot{x}(n)\right)$$



Equivalent to adding damping
$b = kT/2$ to the virtual wall

Velocity Estimation

- Velocity is not measured and must be estimated: $\dot{x}(n) \approx \frac{1}{T}\left(x(n) - x(n-1)\right)$

- Force becomes:
$$F(n) = -k\left(x(n) + \frac{T}{2}\dot{x}(n)\right)$$
$$= -k\left(\frac{3}{2}x(n) - \frac{1}{2}x(n-1)\right)$$

- Other issues
  - Computation delay
  - Quantization
  - How to simulate?