Virtual Wall

- **Software loop**
  - read position from encoder
  - compute force $F = 0$ or $F = kx$
  - set PWM duty cycle

- **Rotary motion**
  - degrees $\leftrightarrow$ encoder count
  - torque $\leftrightarrow$ PWM duty cycle
  - 1 degree into wall $\leftrightarrow$ 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 \( \frac{1}{2} \) sample delay
⇒ spring adds energy

\[ W = \int F \, dx \]
Half Step Prediction

• Predict puck position one step ahead and use spring law

\[ F(n) = -k(x(n) + \dot{x}(n+1))/2 \]

\[ \dot{x}(n+1) \approx x(n) + \dot{x}(n)T \]

\[ F(n) = -k(x(n) + \frac{T}{2} \dot{x}(n)) \]

Equivalent to adding damping \( b = kT/2 \) to the virtual wall
Velocity Estimation

• Velocity is not measured and must be estimated:

\[ \dot{x}(n) \approx \frac{1}{T} (x(n) - x(n - 1)) \]

• 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?