BEENG 122A Project

VAGINAL DILATOR STRESS σ CONTROL SYSTEM

By: German, Ritika, Melina, Stella

TABLE OF CONTENTS

01

INTRO

Device design, control system components

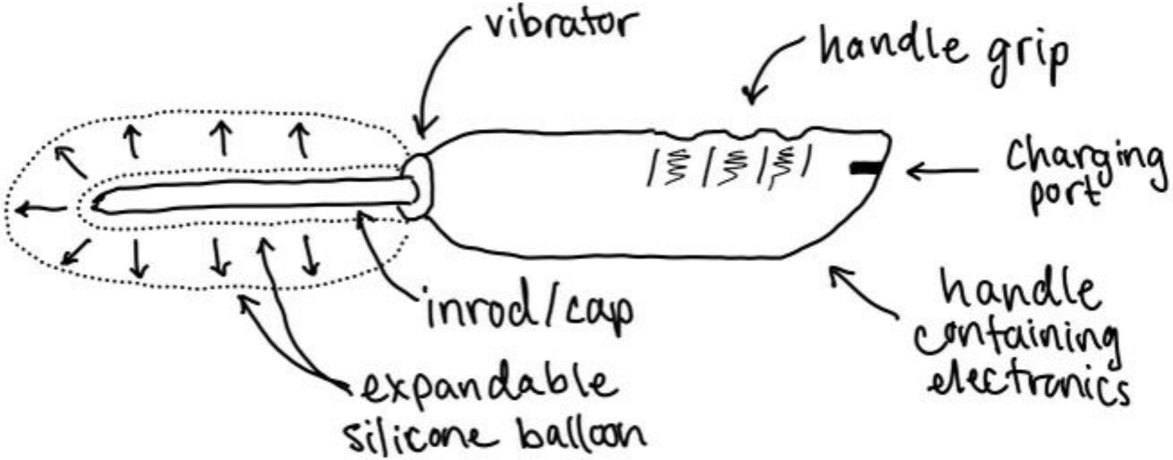
Background

- **Vaginal stenosis**→ disorder characterized by the narrowing + shortening of vaginal canal due to formation of post-radiation fibrous tissue
- **Vaginal dilation**→ mechano-therapeutic treatment of vaginal stenosis
  - pain relief
  - ability to perform post-radiation pelvic examinations
- Closed loop control, negative feedback system models balloon internal volume + the stress exerted on vaginal canal

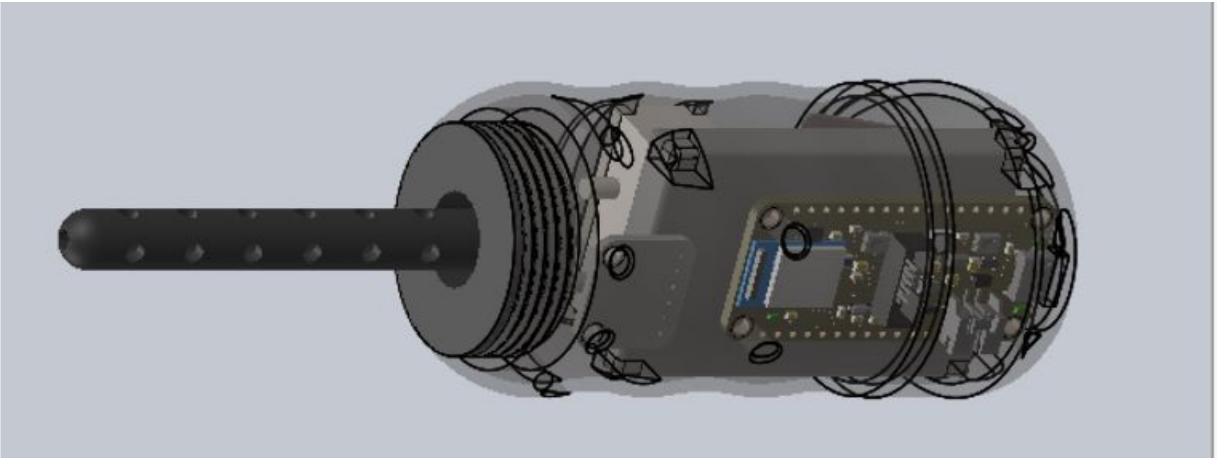
Motivation

- **Current vaginal dilators**
  - Rigid
  - Uncomfortable
  - Discrete dilation
  - Stress→ Scar tissue
- **Expandable dilators** → more comfortable, continuous, controlled dilation
- Control system maintains **target stress** for safe dilation to avoid scarring

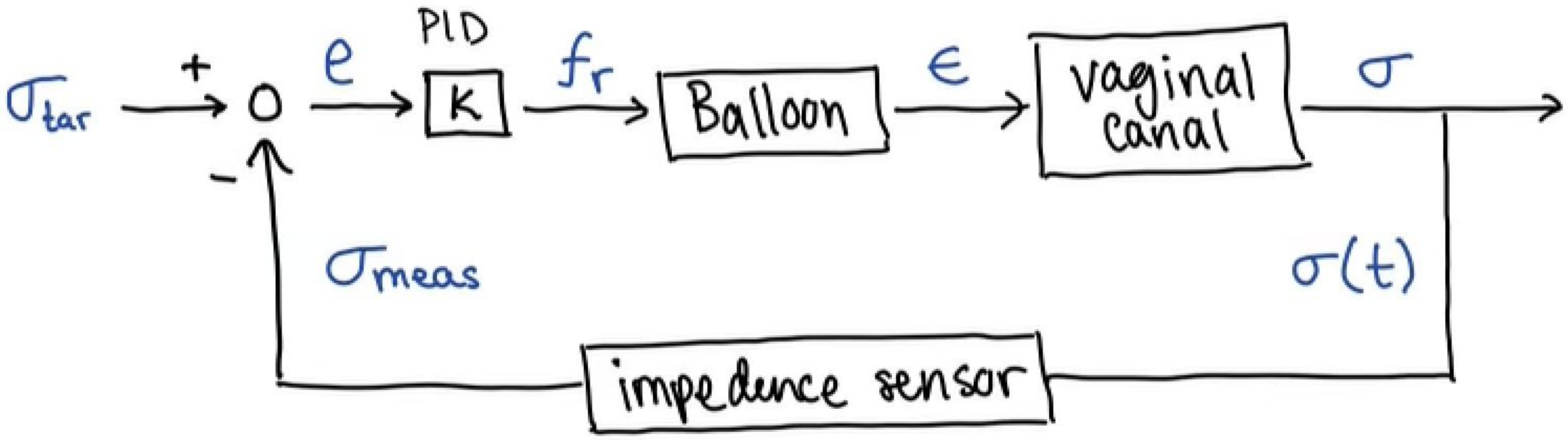
DESIGN SKETCH



CAD MODEL



Stress Control System



Key Assumptions

1. Balloon dilator and vaginal canal are modeled as perfect cylinders with constant height
2. Balloon dilator expands uniformly and radially outwards
3. The vaginal wall tissue is static, viscoelastic and homogeneous and deformation is reversible
   a. Modeled with **Kelvin-Voigt model** for viscoelastic materials
4. Can approximate the $r^2(t)$ as a linear function
5. Balloon is inflated with saline rather than air
6. Thickness of the balloon is negligible

02

EQUATIONS

ODE's and derivation of transfer functions

EQUATION CONCEPTS

PID

- error = $\sigma_{tar} - \sigma_{meas}$
- PID Controller determines flow rate (f_r) of saline
  - Proportional

BALLOON

- Volume of balloon =

$$V(t) = \int_0^t f_r(t)dt$$

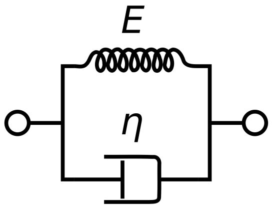
- Change in volume → change in radius of balloon

$$V(t) = \pi r_B^2 h_B \rightarrow V(t) = 2\pi r_B h_B$$

Linear approximation of r_B^2

VAGINAL WALL

- Balloon exerts a force on vaginal canal → strain
- Vaginal tissue follows viscoelastic Kelvin-Voigt Model



SYSTEM OF ODE's

Target Stress: $\sigma_{tar} = 1\ kPa$

Measured time: $\tau_{meas} = 0.5\ sec$

Proportion control: $K_P = 5$

Radius of balloon: $r_B = 0.7\ cm$

Length of dilator: $h_B = 3.4\ cm$

Radius of vaginal canal: $r_{VC} = 1.5\ cm$

Modulus of vaginal tissue: $E_{VC} = 4.3\ kPa$

Viscosity of vaginal tissue: $\eta_{VC} = 2.9\ kPa$

Measurement Time Delay

$$\frac{d\sigma_{meas}}{dt} = \frac{1}{\tau_{meas}}[\sigma(t) - \sigma_{meas}(t)]$$

Error

$$e(t) = \sigma_{tar}(t) - \sigma_{meas}(t)$$

Flow Rate

$$f_r(t) = K_P e(t)$$

Volume of Balloon

$$V(t) = \pi r_B^2 h_B \rightarrow V(t) = 2\pi r_B h_B$$

Volume vs Flow Rate

$$V(t) = \int_0^t f_r(t)dt$$

Stress vs Strain

$$\sigma(t) = E_{VC}\epsilon(t) + \eta_{VC}\frac{d}{dt}\epsilon(t)$$

Strain in terms of radius

$$\epsilon(t) = \frac{r(t)-r_B}{r_B}$$

TRANSFER FUNCTIONS

PID

$$H_{PID}(s) = \frac{F_r(s)}{E(s)} = K_P$$

SENSOR

$$H_{IS}(s) = \frac{\Sigma(s)}{\Sigma_{meas}(s)} = \frac{1}{1+\tau_{meas} s}$$

BALLOON

$$H_B(s) = \frac{R(s)}{F_r(s)} = \frac{1}{2\pi h_B s}$$

VAGINAL WALL

$$H_{VC}(s) = \frac{\Sigma_{meas}(s)}{R(s)} = \frac{E_{VC} + \eta_{VC} s}{r_B}$$

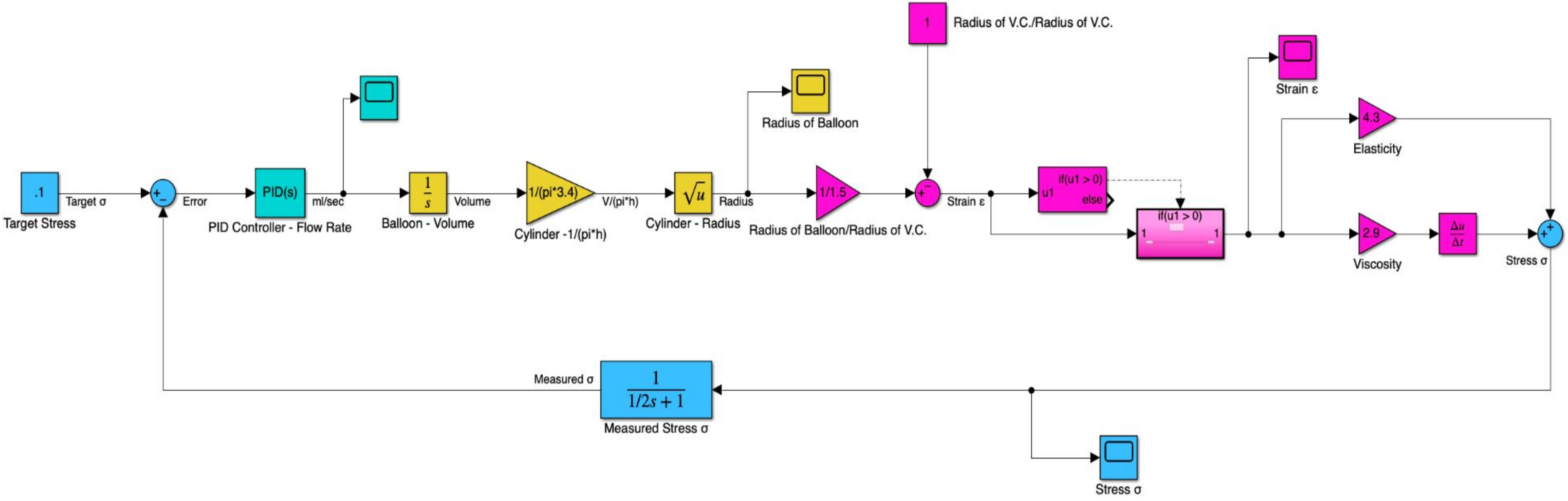
$$H(s) = K_P \cdot \frac{E_{VC}}{2\pi h_B r_B} \cdot \frac{1+\frac{\eta_{VC}}{E_{VC}} s}{s(1+\tau_{meas} s)}$$

03

MODEL ANALYSIS

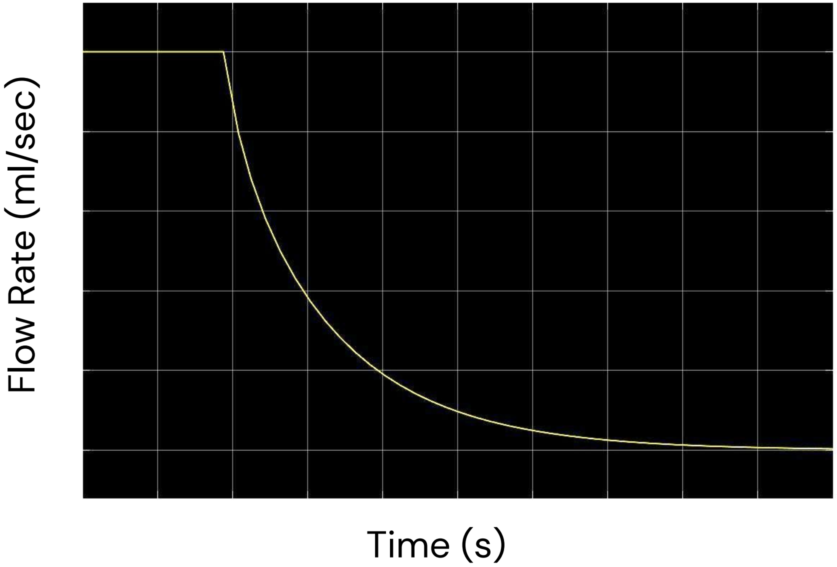
Block diagram, output responses, bode plot, stability

Simulink Block Diagram

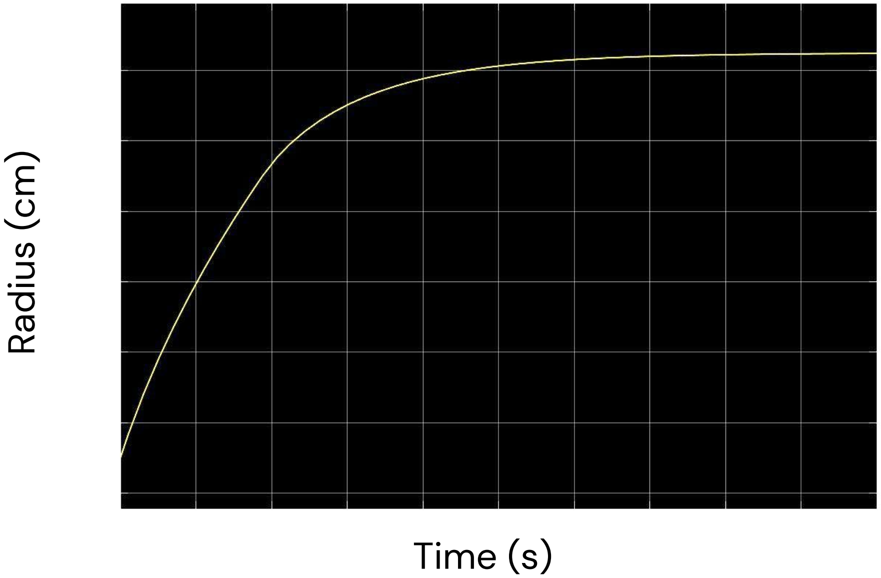


OUTPUT RESPONSE

Flow Rate

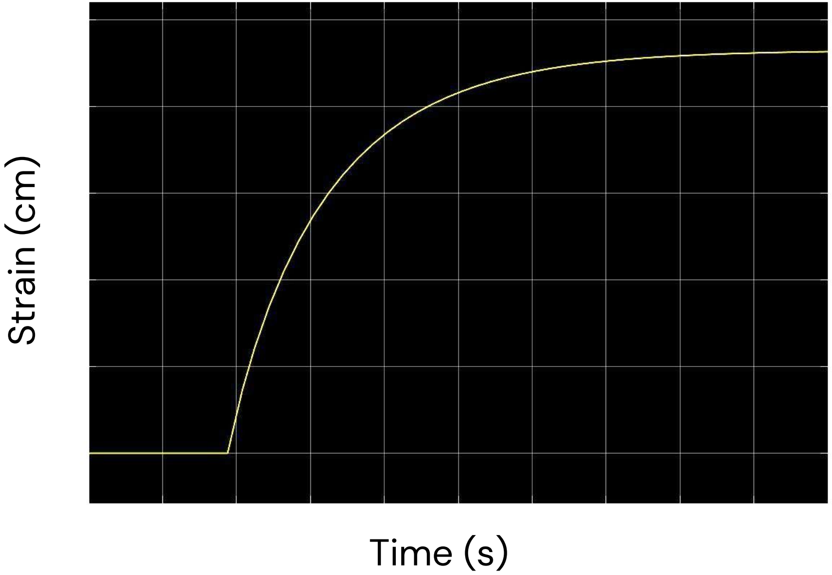


Radius

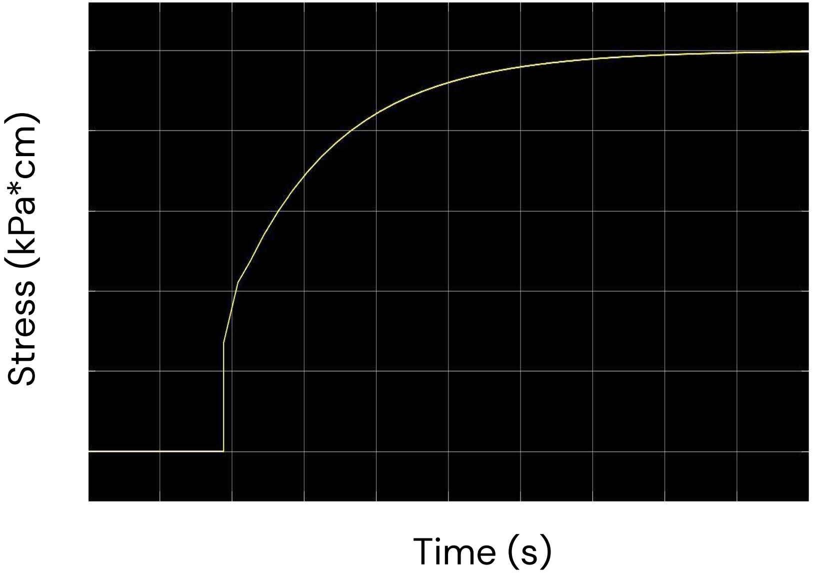


OUTPUT RESPONSE

Strain



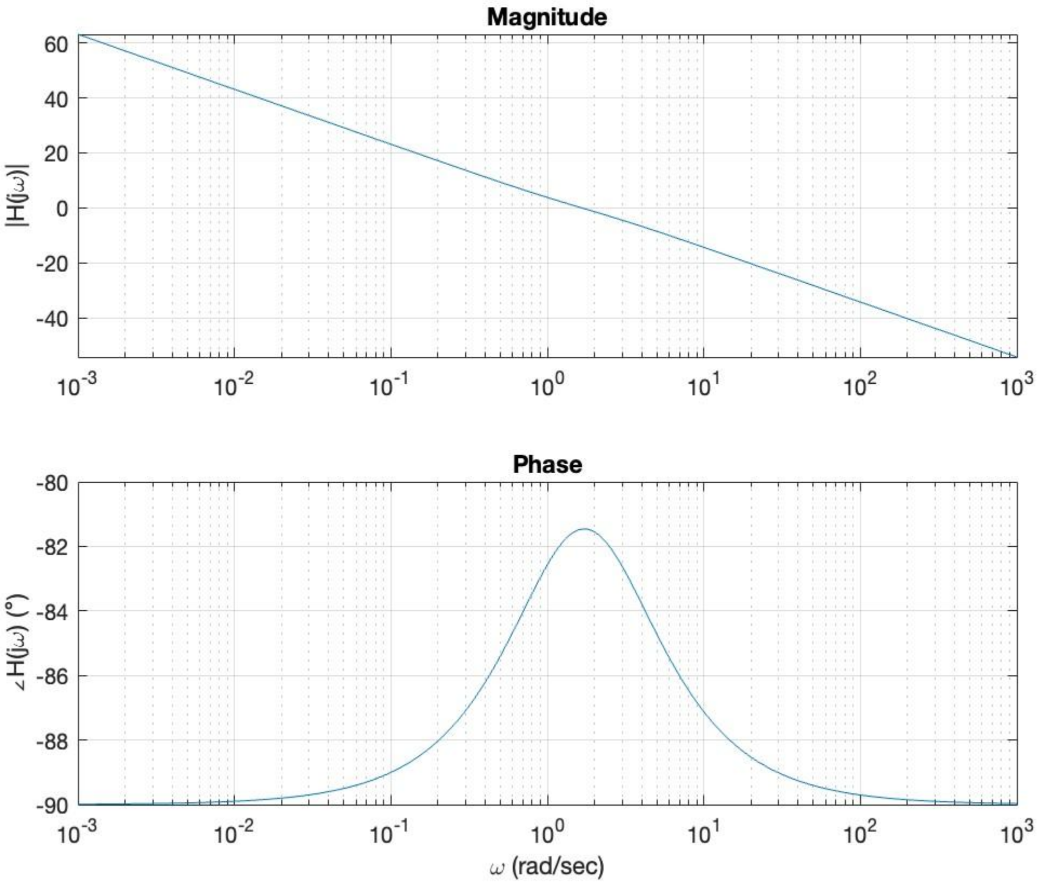
Stress



Bode Plots

$$H(s) = 1.4377 \cdot \frac{1 + 0.6744\, s}{s\,(1+0.5\, s)}$$

- First Order
- One Zero at ~ −1.48
- Two Poles at 0 and −2
- Stable - no positive real pole components
- Phase margin is 90º



04

SUMMARY

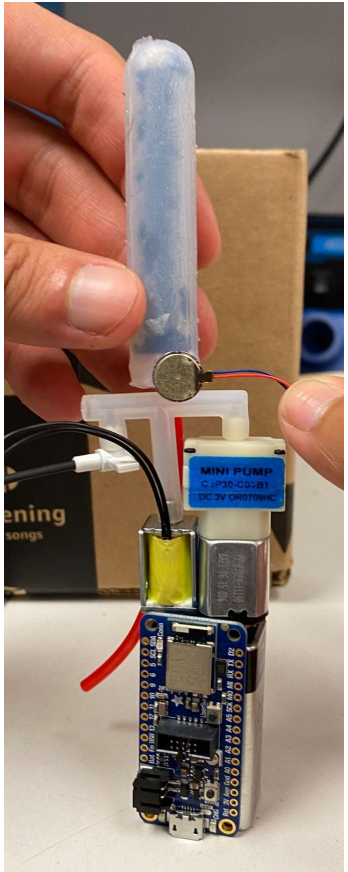
Errors, Discussion and Conclusions

Errors in Simulation

- Vaginal canals and the balloon are not perfect cylinders
    - Some parts of the vagina may experience more stress/strain than others
    - There is vertical/lengthwise expansion in addition to radial expansion
- $r(t)^2$ approximation
    - Not valid when r is much bigger or smaller than r=1

Conclusions

- **Goals:**
  - Dilator does not impart harmful stress on vaginal canal
  - Expands and deflates gradually
- **P Controller** → more gradual expansion, no overshoot, stable system
- Implement in Senior Design Project



Future Directions

- Using air instead of saline
  - As pressure $\uparrow$, motor output $\downarrow$
- Better viscoelastic model for vaginal tissue
  - Experimentally determine parameters
  - Account for slightly irreversible deformation
- Diagnostic application
  - Map out extent of stenosis

Thank you!

Any Questions?