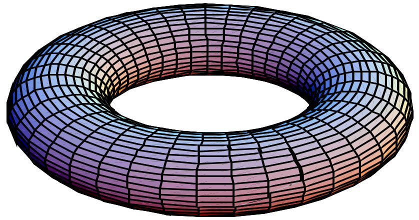
Variable Structure Control of a Steam Power Plant

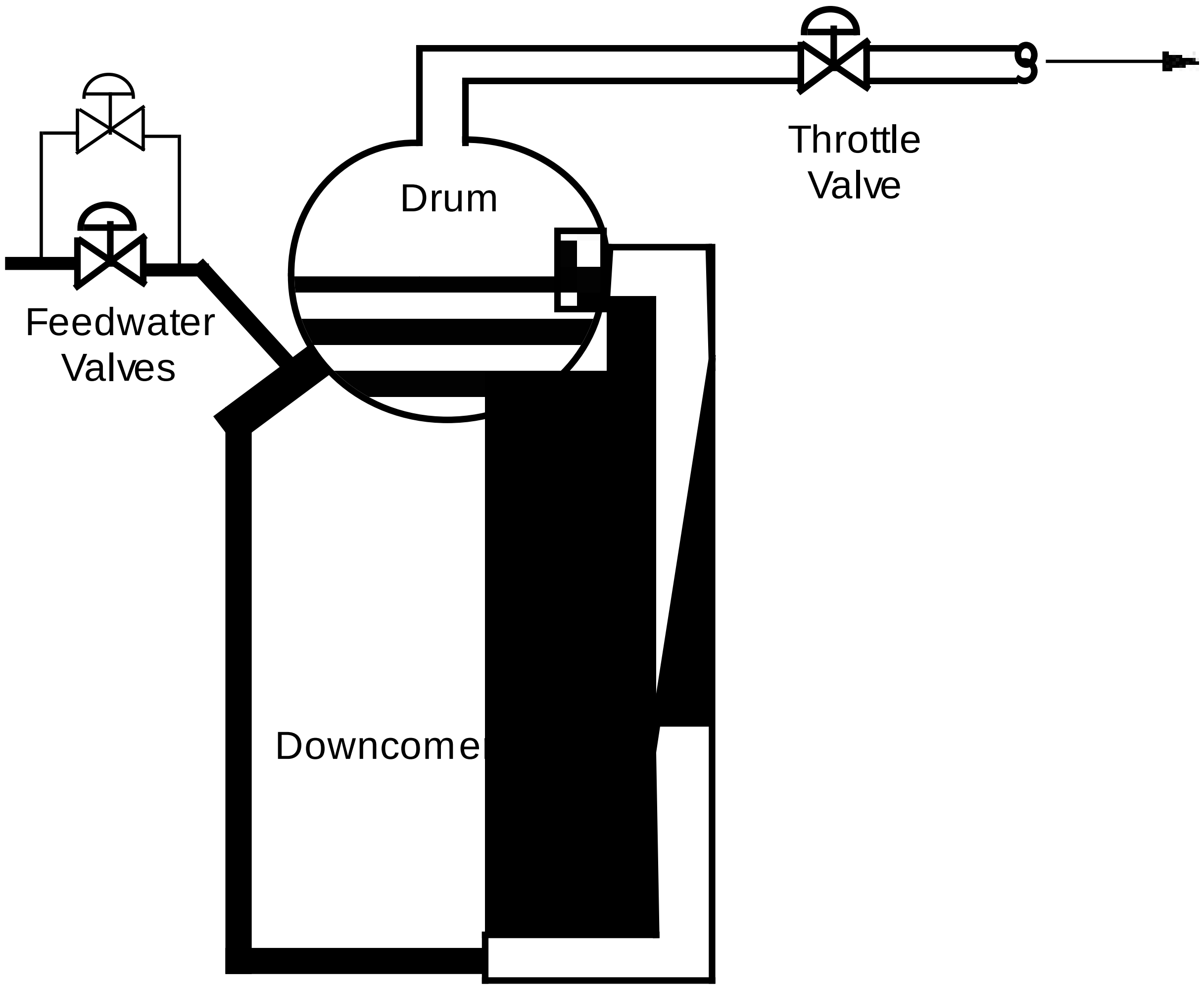
Harry G. Kwatny
Department of Mechanical Engineering & Mechanics
Drexel University



Outline

- Linear Tracking & Disturbance Rejection
- Variable Structure Servomechanism
- Nonlinear Tracking & Disturbance Rejection

Example: Drum Level Control



Drum Level, 2

N	number of riser sections
Ldo,L	downcomer length and riser section length (total riser length/N)
Ado,A	downcomer, riser cross section areas
wi	mass flow rate at ith node
Pi	pressure at ith node
Ti	temperature at ith node
si	aggregate entropy at ith node
vi	specific volume at ith node
wr,wdc,ws	mass flow rates, riser, downcomer and turbine, respectively
vdf,vdg	drum specific volume, liquid and gas, respectively
Pd	drum pressure
Td	drum temperature
V	total drum volume
Vw	volume of water in drum
xd	net drum quality, xd=Vw/V
ws0	throttle flow at rated conditions
Pd0	drum pressure at rated conditions
At	normalized throttle valve position, at rated conditions At=1

Drum Level, 3

$$u_1 = q,\ u_2 = \omega_e,\ u_3 = A_t$$

$$\frac{d\omega_{av}}{dt} = f_1(\omega_{av}, s_1, s_2, s_3, P_{av}, P_d)$$

$$\frac{ds_1}{dt} = f_2(\omega_{av}, s_1, P_{av}) + g_{21}(P_{av}, s_1)u_1 + g_{22}(\omega_{av}, P_d)u_2$$

$$\frac{ds_2}{dt} = f_3(\omega_{av}, s_1, s_2, P_{av}) + g_{31}(P_{av}, s_2)u_1$$

$$\frac{ds_3}{dt} = f_4(\omega_{av}, s_2, s_3, P_{av}) + g_{41}(P_{av}, s_3)u_1$$

$$\frac{ds_4}{dt} = f_5(\omega_{av}, s_3, s_4, P_{av}) + g_{51}(P_{av}, s_4)u_1$$

$$\frac{dP_{av}}{dt} = f_6(\omega_{av}, s_1, s_2, s_3, s_4, P_{av}, P_d) + g_{61}(\omega_{av}, s_1, s_2, s_3, s_4, P_{av})u_1$$

$$\frac{dP_d}{dt} = f_7(\omega_{av}, s_1, s_2, s_3, s_4, P_{av}, P_d, V_w) + g_{71}(\omega_{av}, s_1, s_2, s_3, s_4, P_{av}, P_d, V_w)u_1 + g_{72}(P_d, V_w)u_2 - g_{73}(P_d, V_w)u_3$$

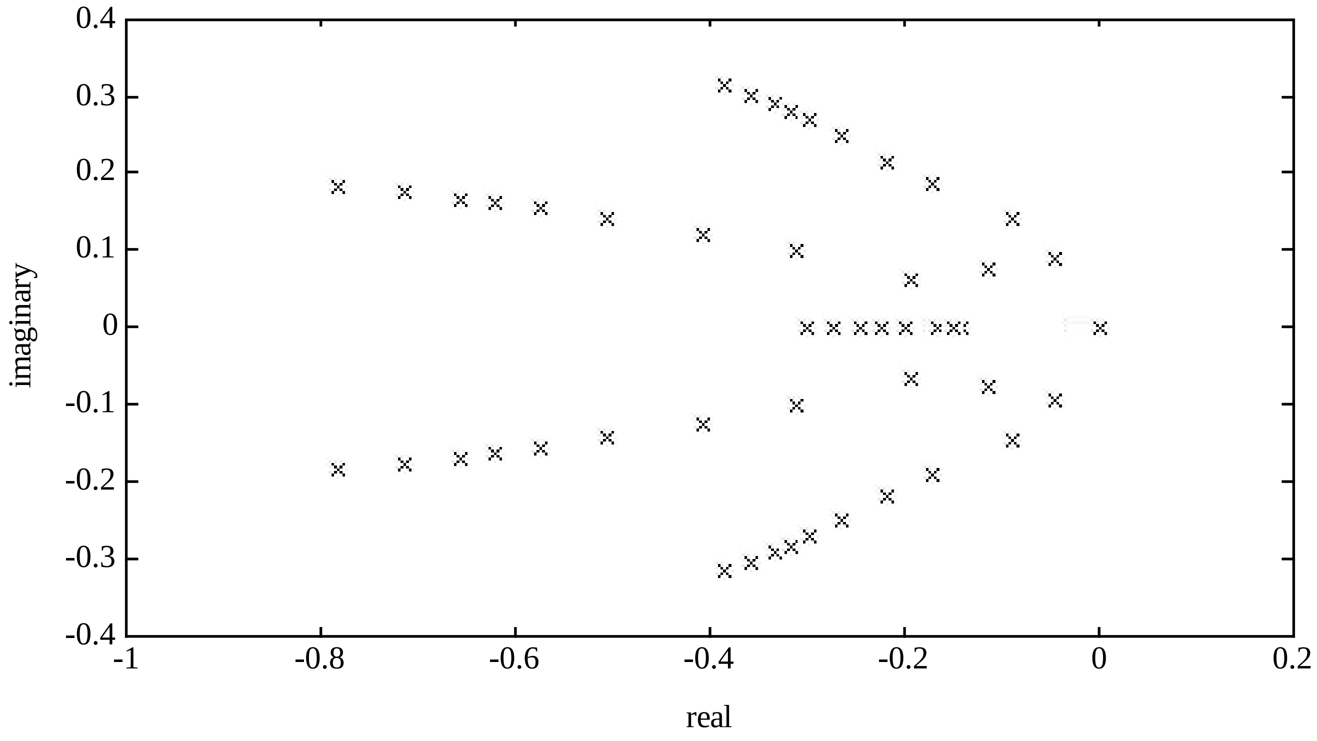
$$\frac{dV_w}{dt} = f_8(\omega_{av}, s_1, s_2, s_3, s_4, P_{av}, P_d, V_w) + g_{81}(\omega_{av}, s_1, s_2, s_3, s_4, P_{av}, P_d, V_w)u_1 + g_{82}(P_d, V_w)u_2 - g_{83}(P_d, V_w)u_3$$

$$y_1 = P_d,\quad y_2 = ,= h_2(V_w),\quad y_3 = \omega_s = h_3(P_d) + d_3(P_d)u_3$$

Drexel UNIVERSITY

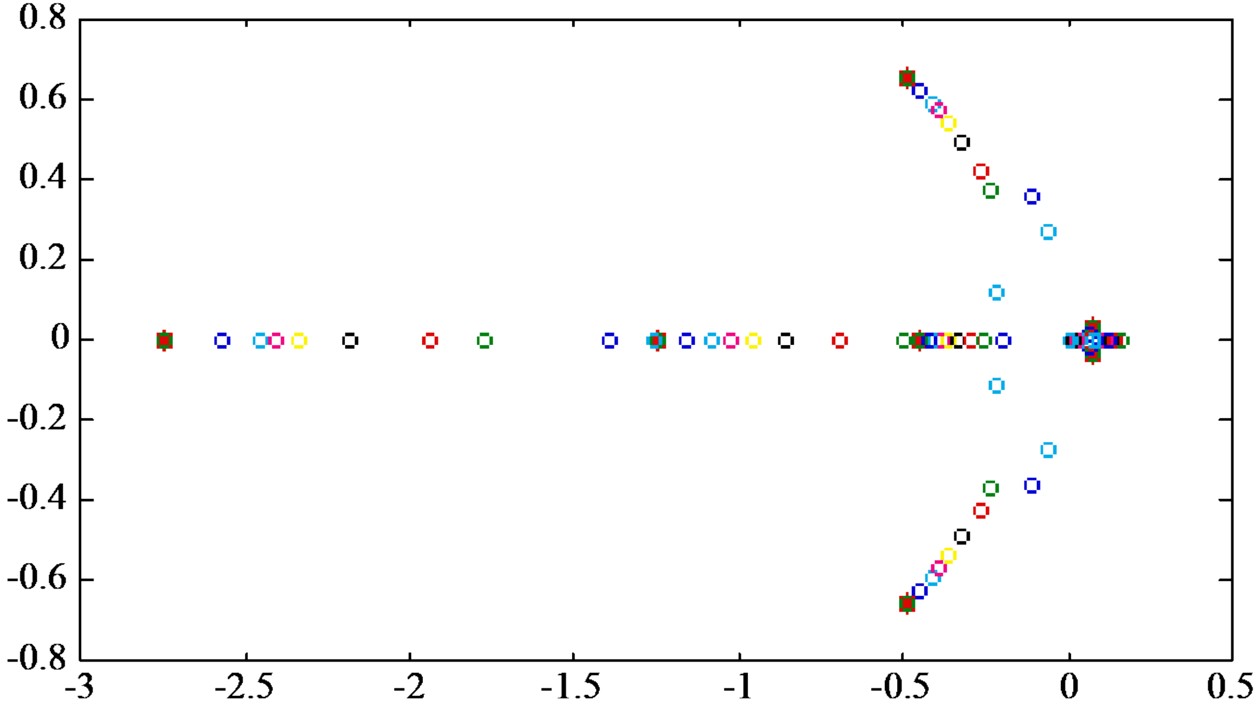
Linearized Dynamics, Poles

Poles as a function of load level, 5%-100%



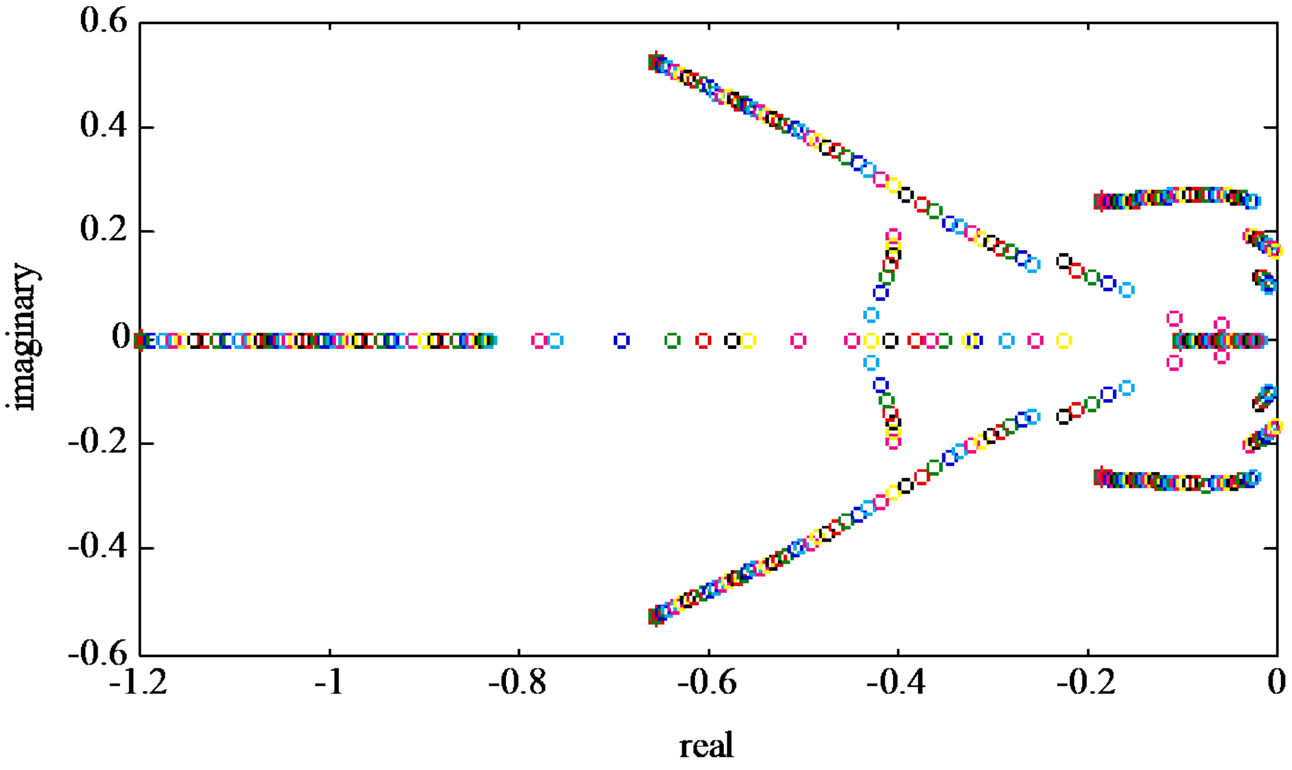
Linearized Dynamics, Zeros

$$\omega_e \rightarrow \ell$$



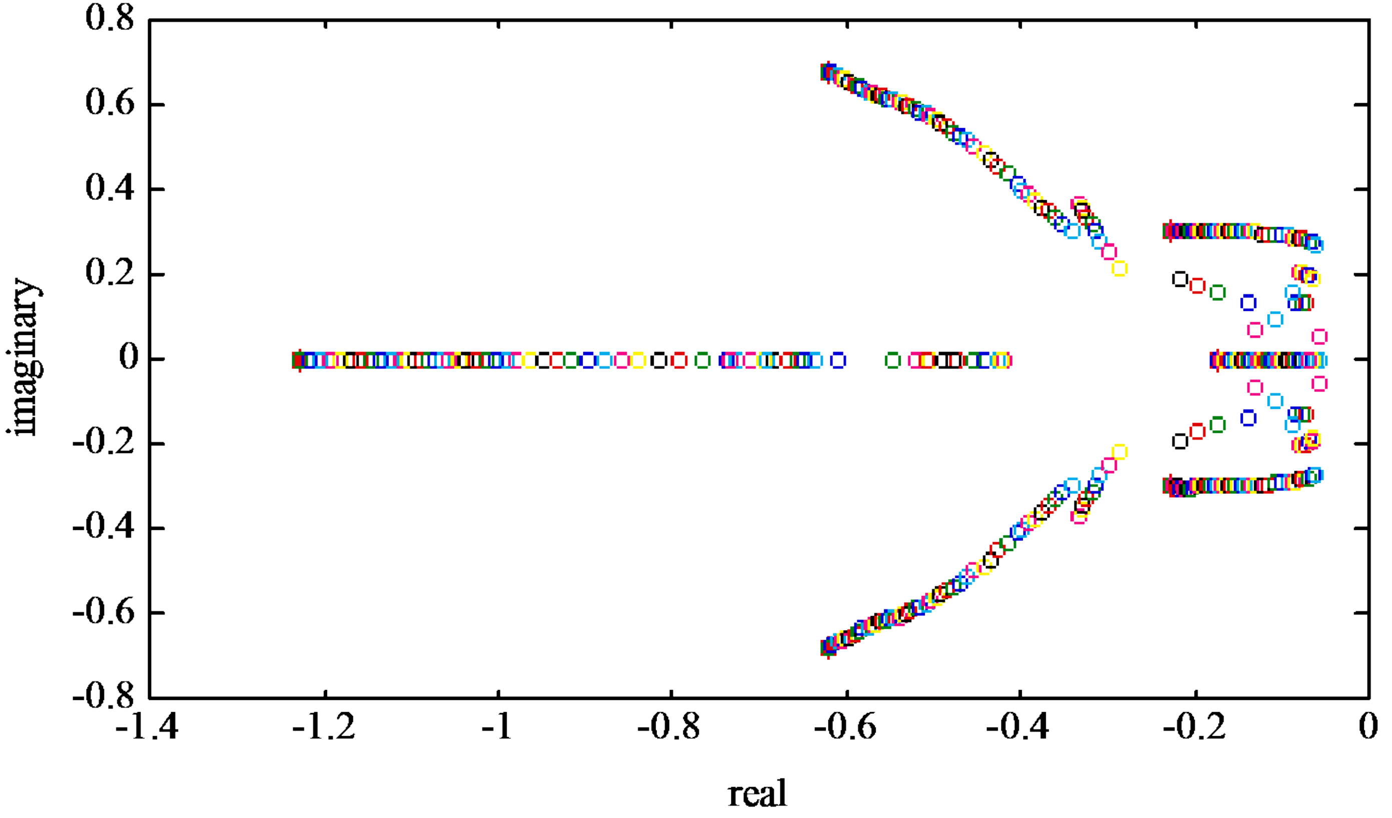
Transmission Zeros

$$\omega_e, A_t \rightarrow P_d, \ell$$

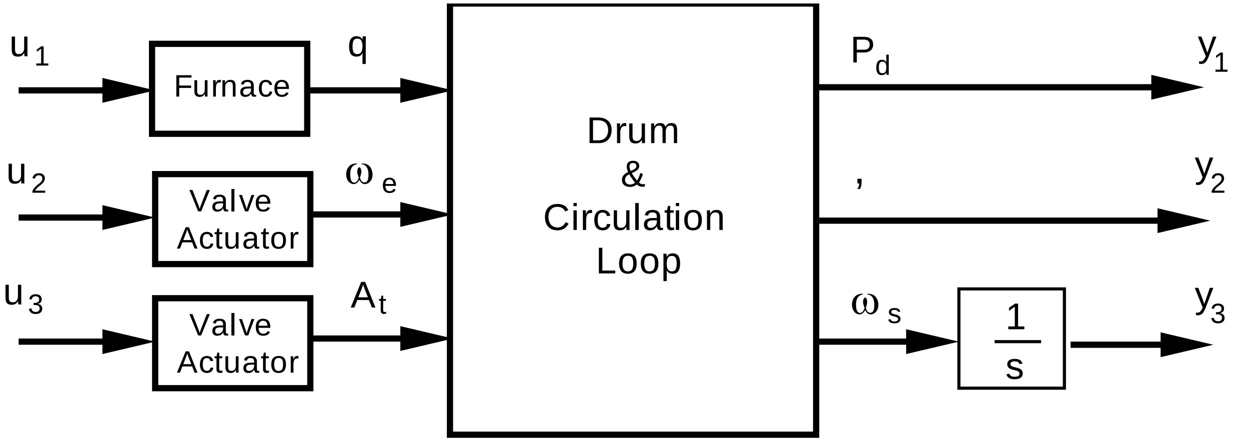


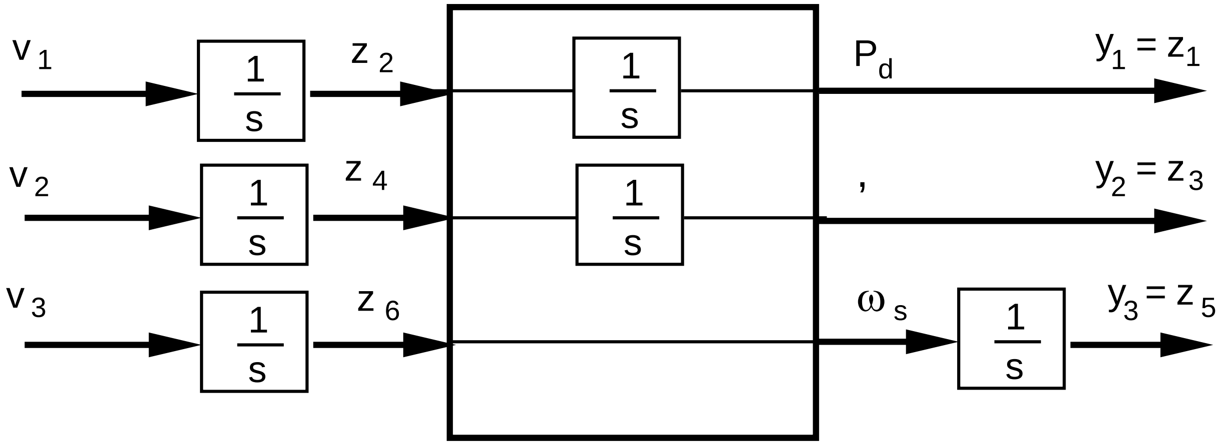
Transmission zeros

$$Q, \omega_e, A_t \rightarrow P_d, \ell, \omega_s$$



Drum Level, Normal Form





Drum Level, Switching Controller

$$s_1 = 0.5z_1 + \dot{z}_1 \qquad z_1 = \left(P_d - \overline{P}_d\right)/P_d^*$$

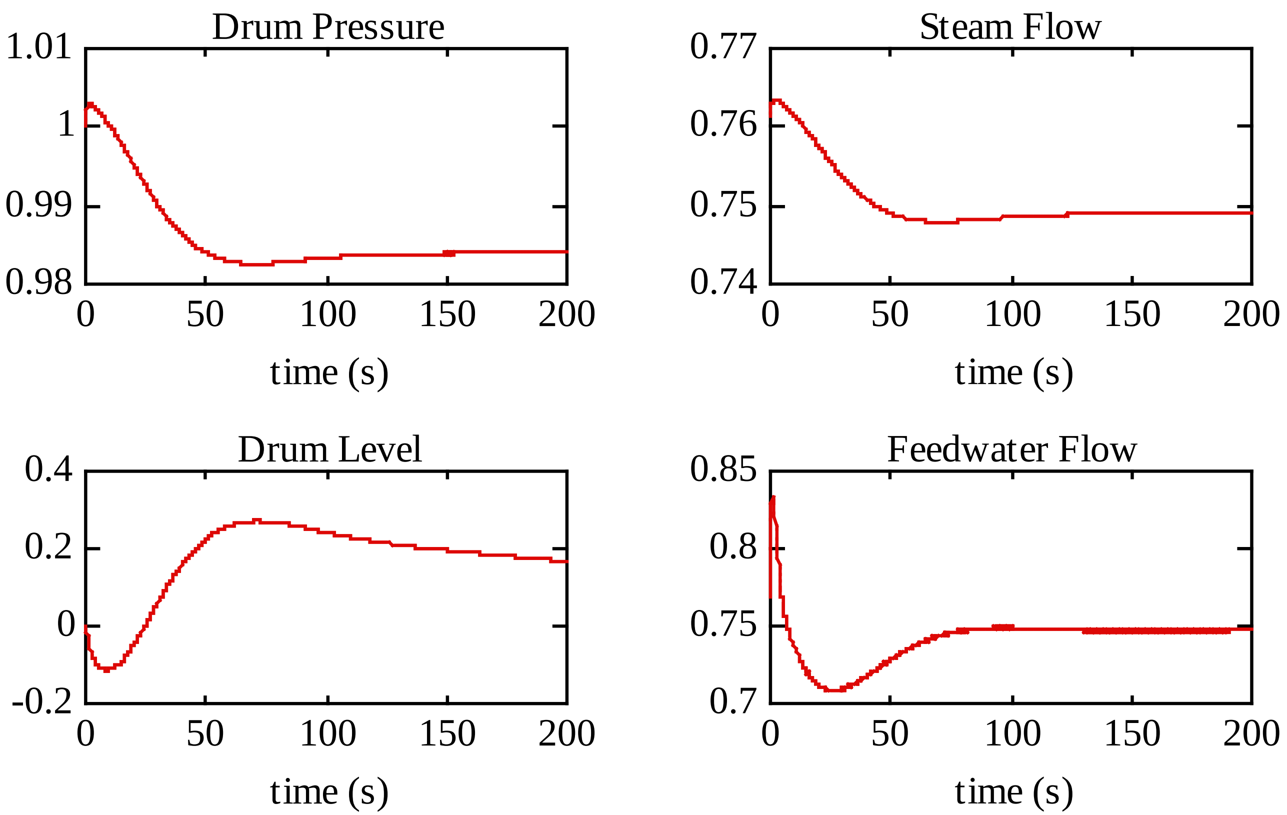
$$s_2 = 0.5z_2 + \dot{z}_2 \qquad z_2 = \ell$$

$$s_3 = 0.0001z_3 + 0.02\dot{z}_3 \qquad z_3 = \int\left(\omega_s - \overline{\omega}_s\right)/\omega_s^*\, dt$$

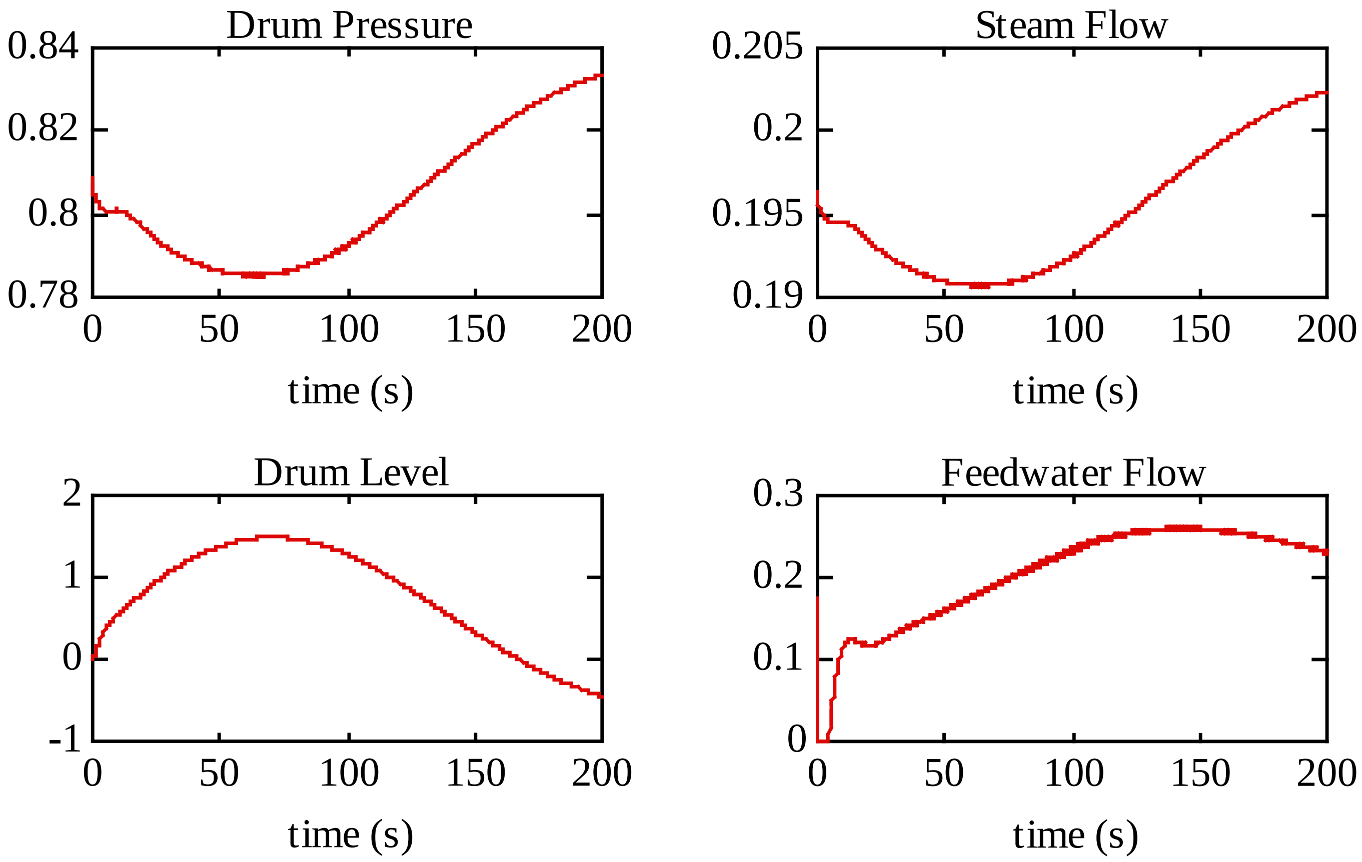
$$u_i\left(x\right) = -\overline{U}_i \operatorname{sgn}\left(s_i^*\right), i = 1, 2, 3 \quad s^* = \rho^T Q s\left(z\right)$$

$$\rho \approx \begin{bmatrix} 0.0071 & 0.09436 & -0.9350 \\ 0.0031 & 0.06793 & -0.1461 \\ 0 & 0 & 0.9176 \end{bmatrix}, Q = \begin{bmatrix} 5 & 0 & 0 \\ 0 & 0.1 & 0 \\ 0 & 0 & 0.001 \end{bmatrix}$$

Drum Level - Conventional, PID with Steam/Water FF
load change 80-75%

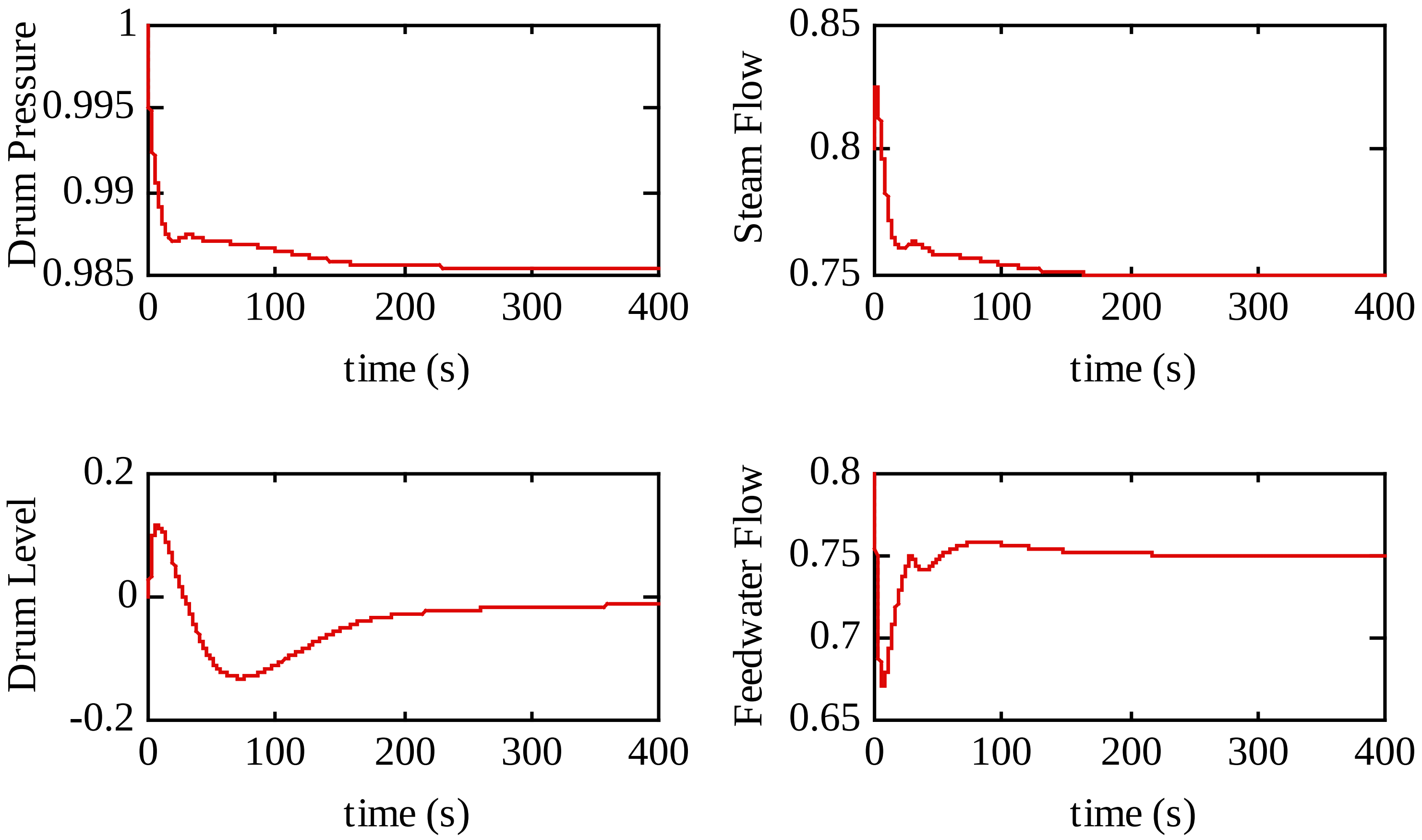


Drum Level - Conventional, PID load change 15-20%



Drum Level - VS Control, load change 80-75%

$$Q, \omega_e, A_t \rightarrow P_d, \ell, \omega_s$$



Drexel UNIVERSITY

Drum Level – VS Control 15-20%