BENCHMARK SIMULATION MODEL IN SIMULINK

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- What was done?
- What model?
- Positioner model
- Pneumatic chamber
- Valve
- End remarks

DAMADICS Workshop

ROBUST METHODS IN FAULT DIAGNOSIS

HULL

January 25, 2002

What was done?

Concise progress report between September and December 2001

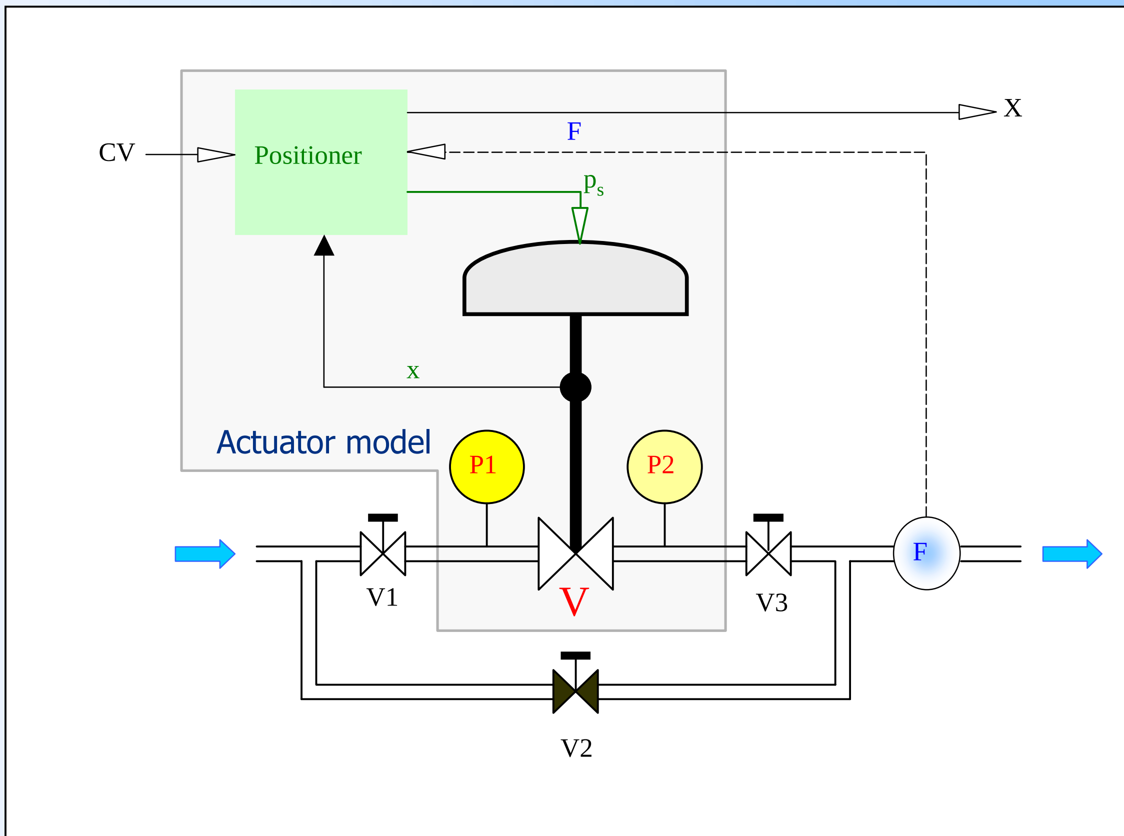
- Improving friction model with stick slip effect
- Tuning control valve model flow coefficient function
- Setting structure of handles for DAMADICS BENCHMARK ACTUATOR LIBRARY
- Preparing draft proposal of DAMADICS BENCHMARK ACTUATOR LIBRARY principles and structure

What model?

- Model of actuator consisting of: positioner, pneumatic motor and control valve
- Model based on physical phenomena description
- Created with many simplifications
- For better use, model general structure reflects hardware of actuator i.e. consists of : Positioner, Pneumatic Servomotor and Control Valve submodels
- Model does not contain: plant, installation and controller modeles
- Integrated with DAMADICS BENCHMARK ACTUATOR LIBRARY as a core of Actuator (Act) block
- Suitable for first phase of testing FDI algorithms prior to testing using process data and pilot industrial implementation
- Upgraded model version introduced in Lisbon Vacation School

What is to be simulated ?

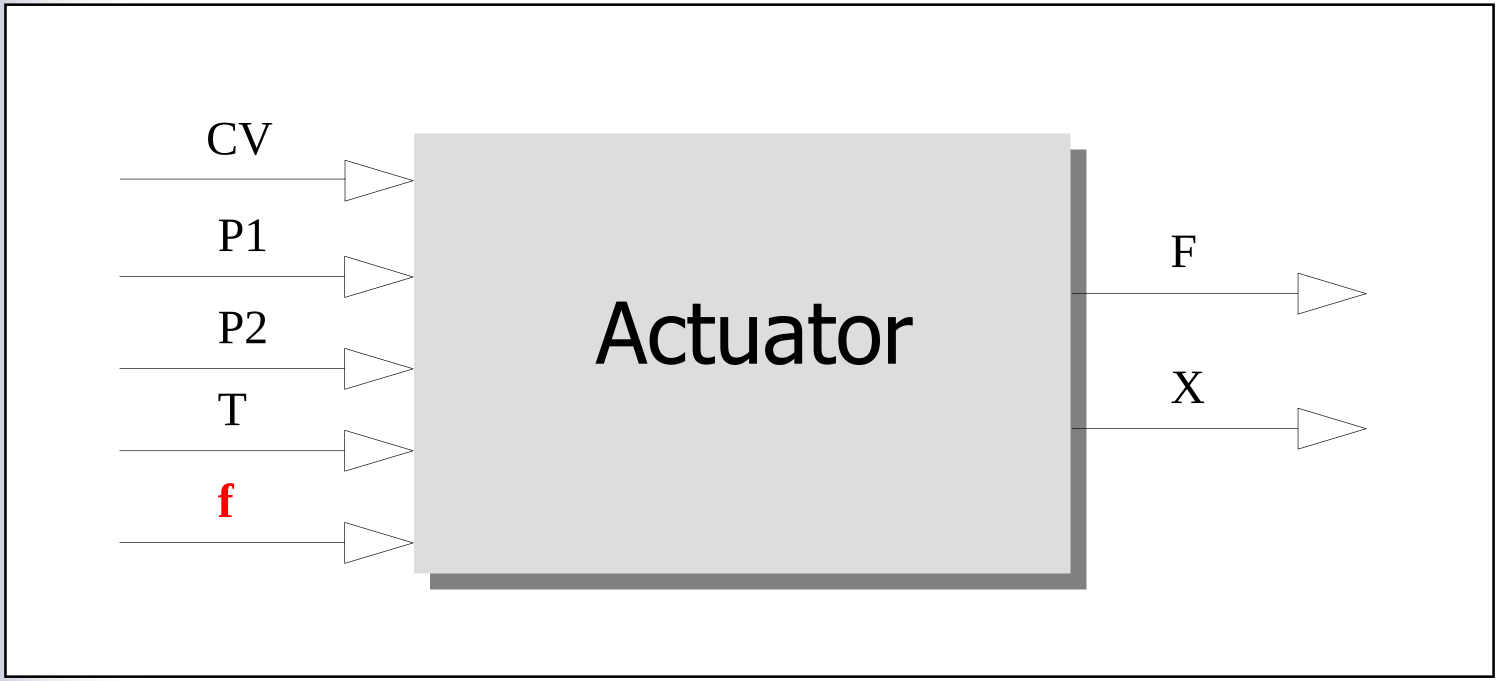
(An assembly of positioner, pneumatic servomotor and control valve)



Actuator assembly and installation

Actuator

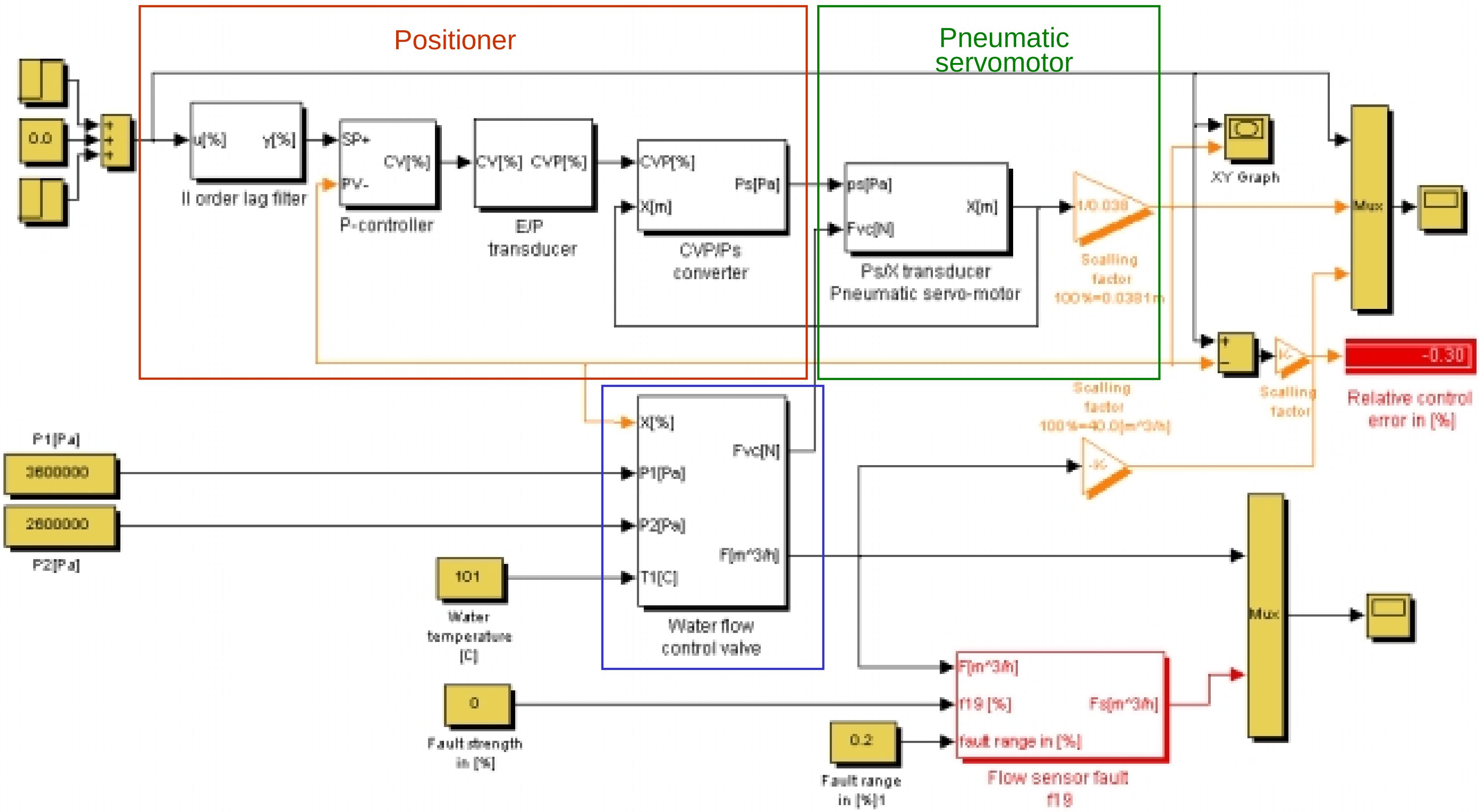
Actuator general block diagram



Vector of faults **f** is used in DAMADICS BENCHMARK ACTUATOR LIBRARY
Vector **f** entries are not further shown in this presentation with some exceptions

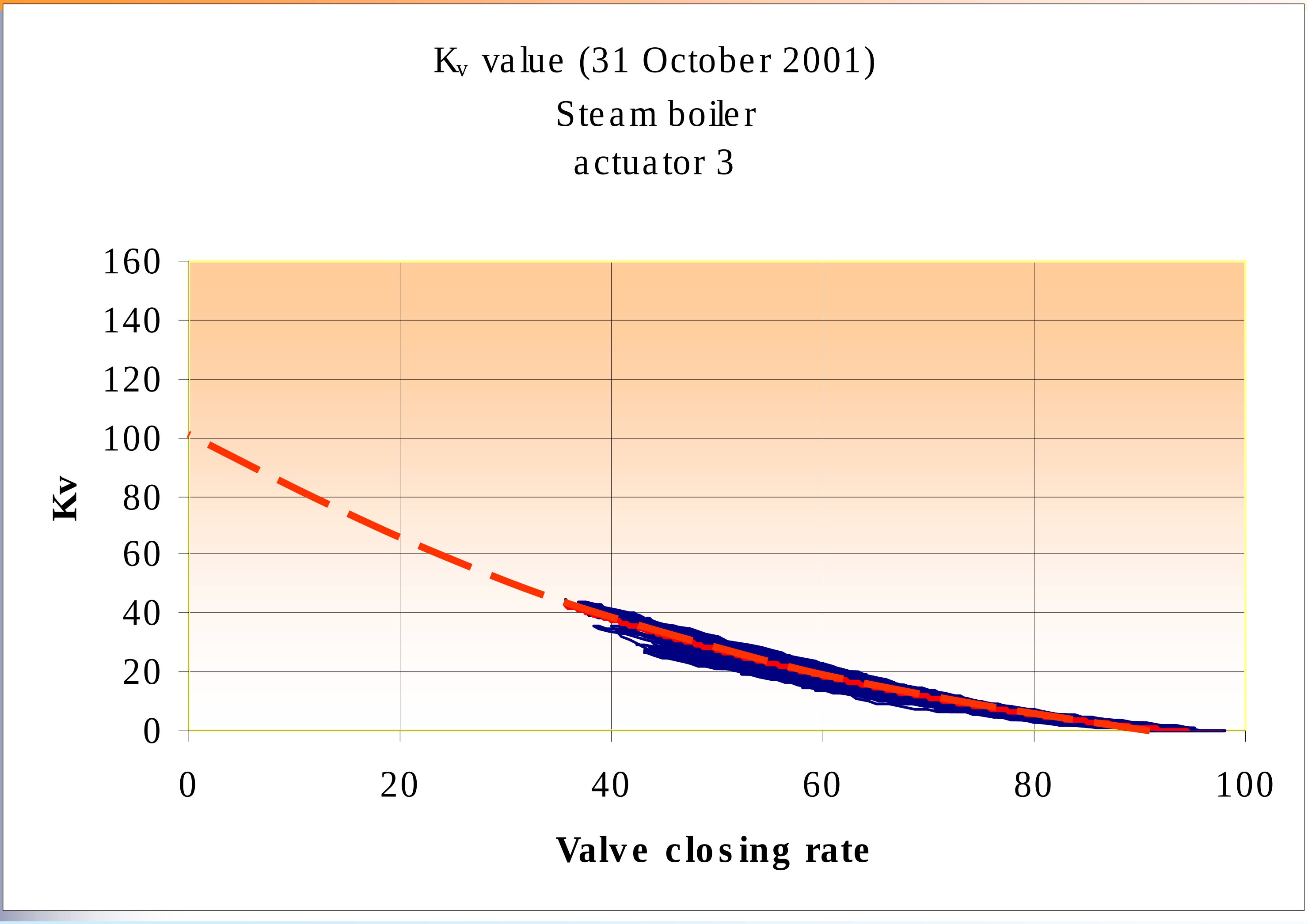
Actuator model (3 constituents)

Model was tuned for simulation of power station boiler



Is model tuning possible from real data?

Kv function reconstruction

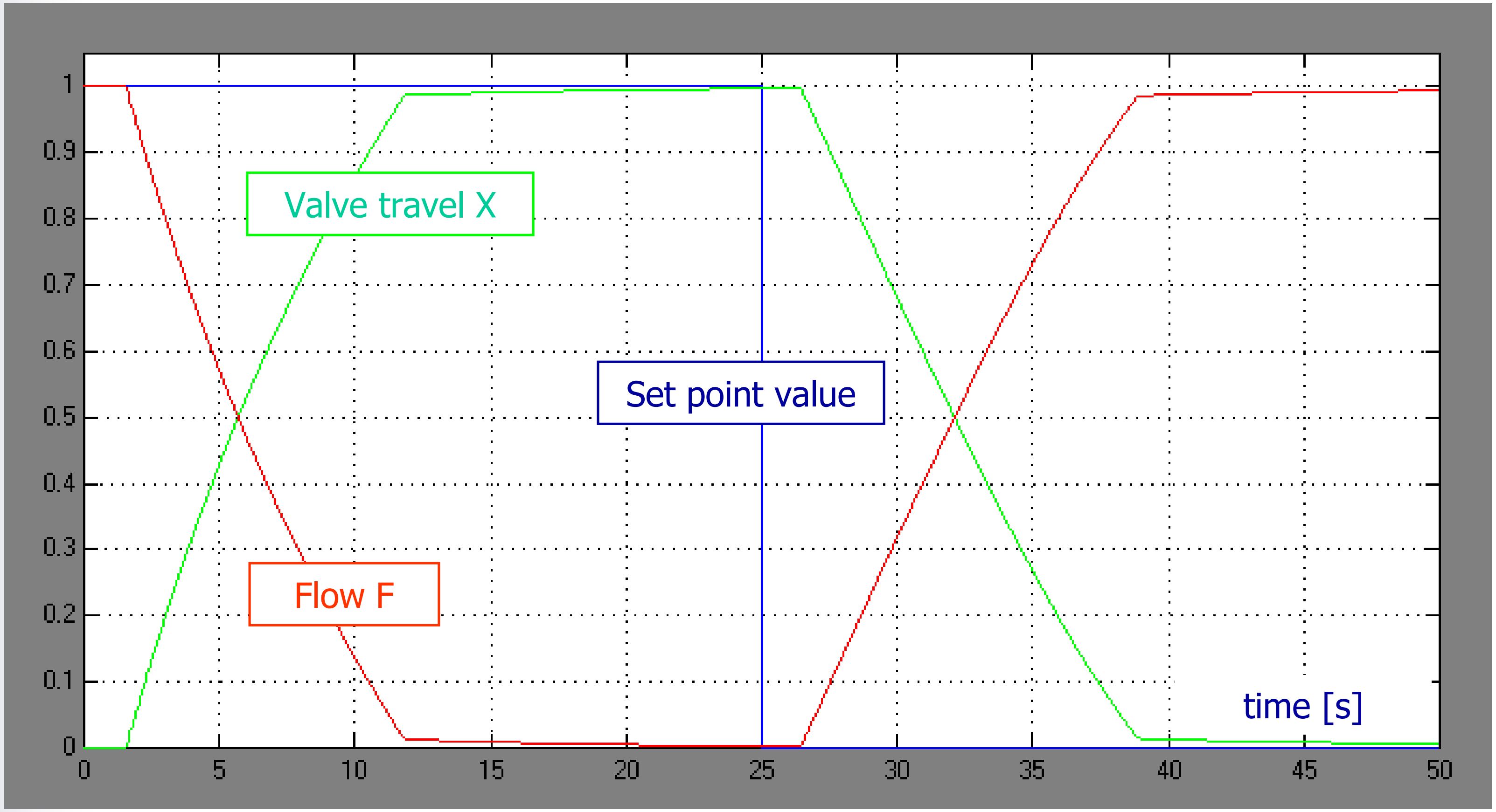


The valve plug travel range of the of control valve may not be sufficiently enough for proper Kv function reconstruction.

Extrapolation technique may be used for example for Kv approximation

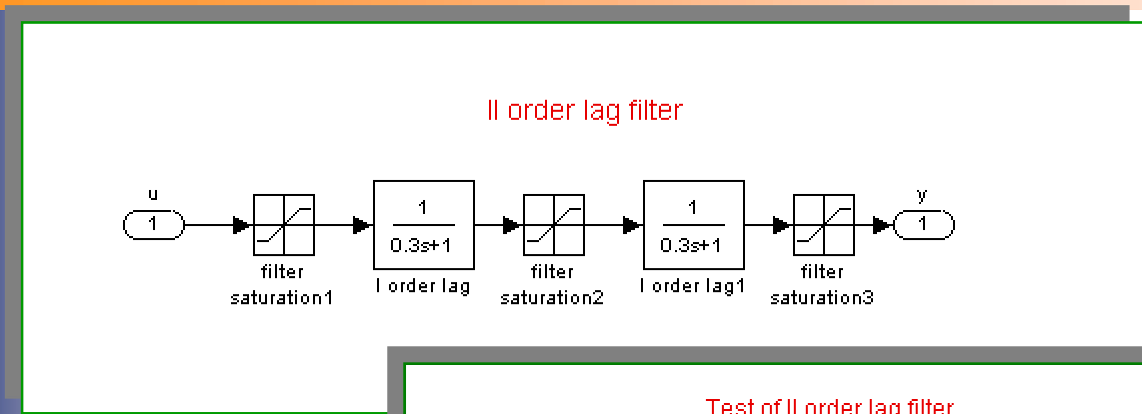
Actuator model

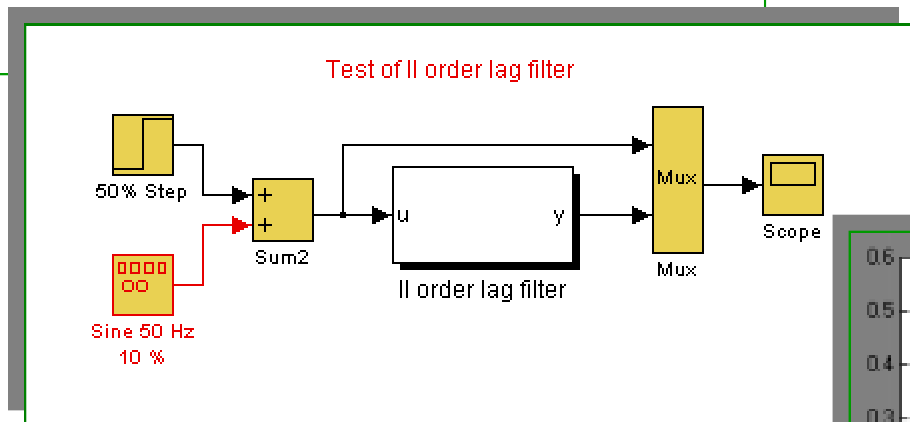
Power station boiler water supply simulation (results)

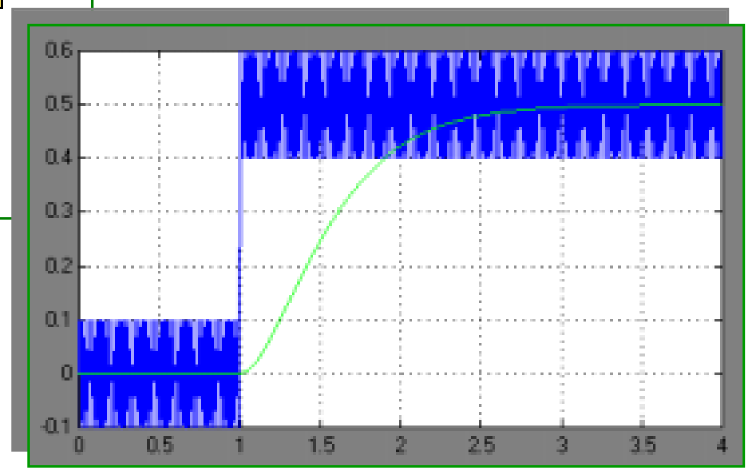


Positioner

Input filter structure and properties



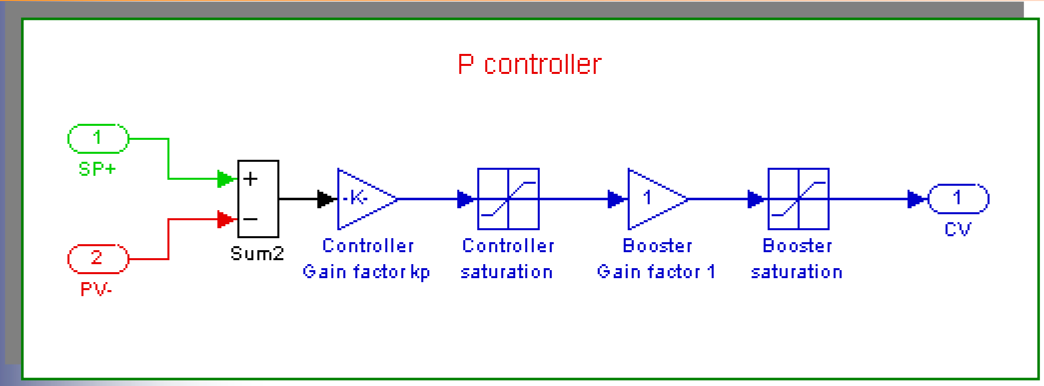


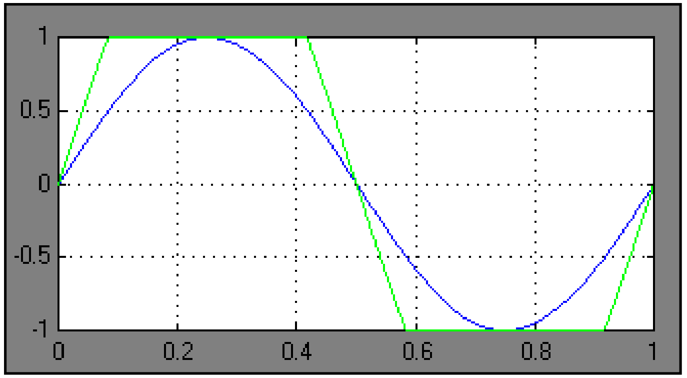


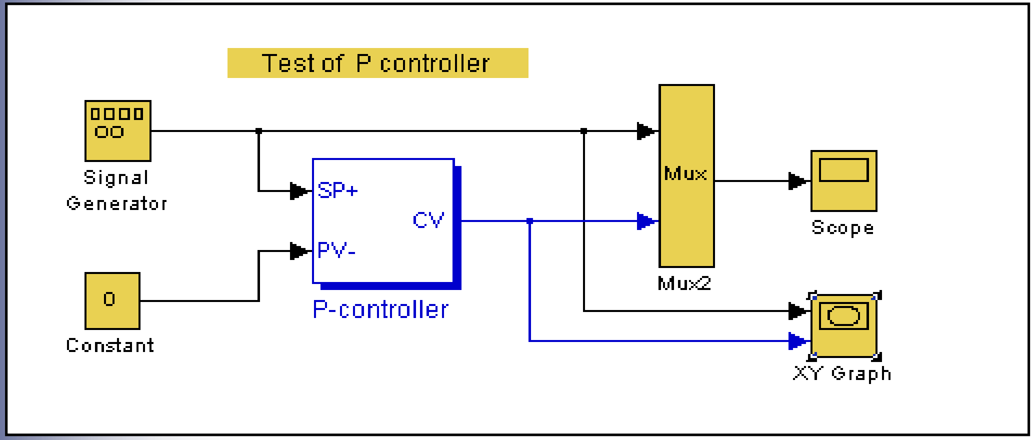
Rejection of mains disturbances
(immunity against EMI)

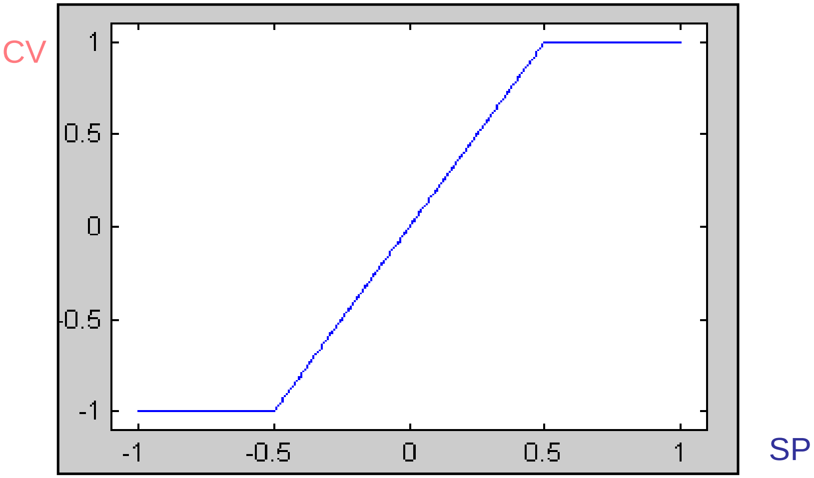
Positioner

Proportional controller







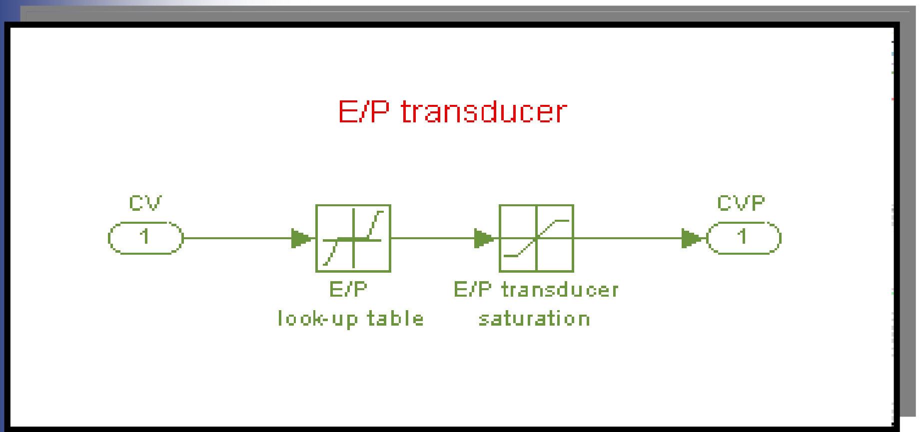


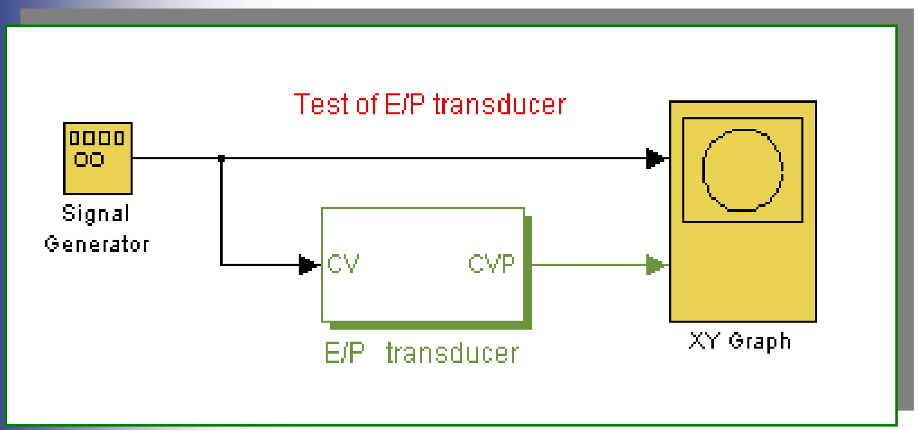
Classical solution

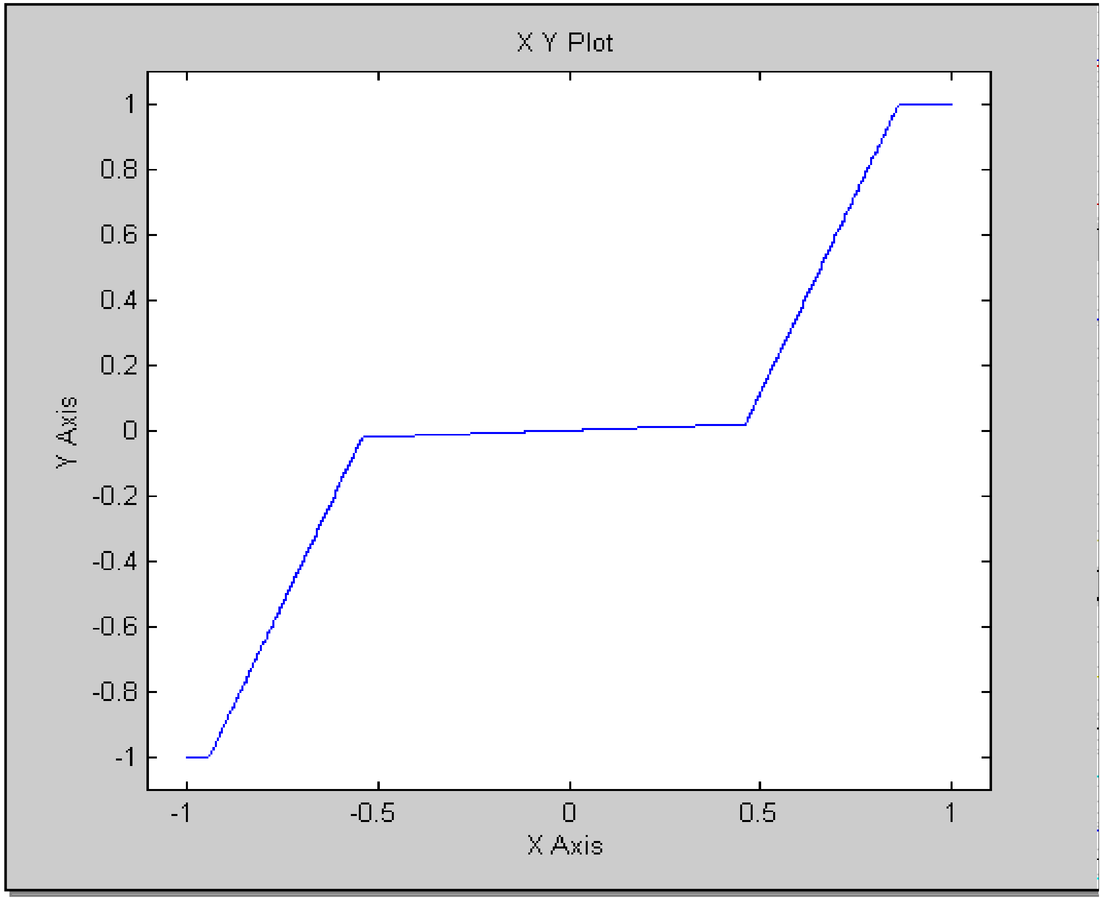
Booster drives electro-pneumatic transducer

Positioner

Electro-pneumatic transducer

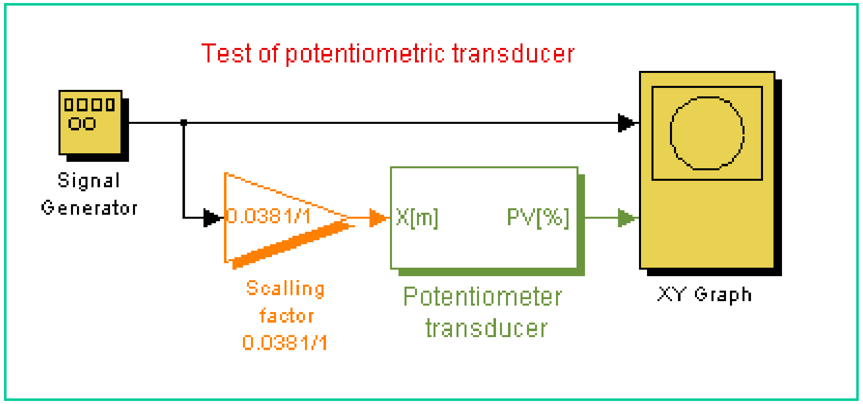


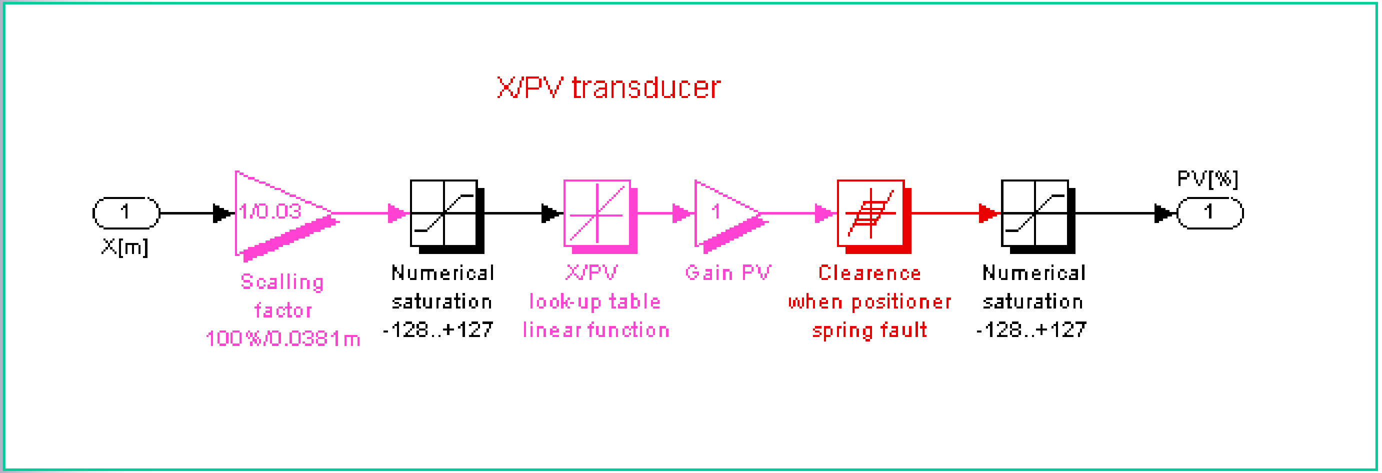




Significant non-linearity and asymmetry

Positioner
Feedback path

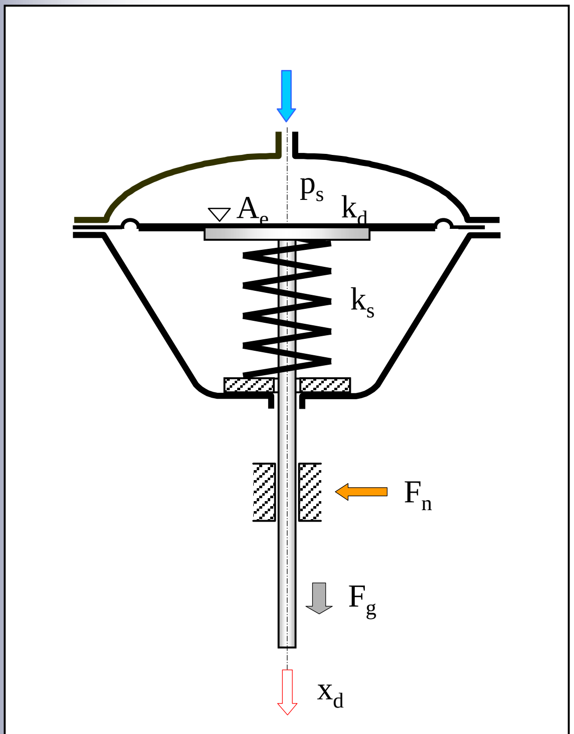




Pneumatic diaphragm servo-motor

(Basic equations)

$$F_{pu} = F_s + F_d + F_f + F_{vc} - F_g$$

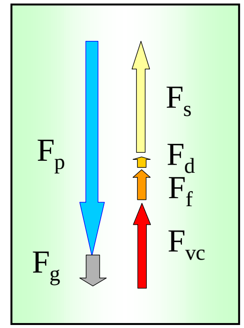


$$F_{pd} = F_s + F_d - F_f + F_{vc} - F_g$$

k_s - spring constant
k_d - diaphragm constant
A_e - effective diaphragm area
p_s - air pressure in chamber
F_n - normal packing force
F_p - active force
F_g - gravity force
F_s - spring compression force
F_d - diaphragm compression force
F_{fv} - viscosity friction force
F_{fC} - Coulomb friction force
F_{vc} - vena-contracta force
F_{dA} - d'Alembert force
x - rod displacement
x_o - initial spring compression stroke
m - mass of rod, valve, diaphragm

Servomotor hysteresis <> friction effect

rod down travel direction



$$\sum_{i=1}^{n} F_i = 0$$

$$F_{pu} - F_{pd} = 2F_f$$

Pneumatic chamber model

Basic equations

Continuity law

$$\dot{m} = \rho \dot{V} + V \dot{\rho} \qquad (1)$$

The classical polytropic relationship

$$\frac{p_1}{\rho_1^{\ n}} = \frac{p_2}{\rho_2^{\ n}} \quad \Rightarrow \quad n = \frac{\dot{p}/p}{\dot{\rho}/\rho} \qquad (2)$$

From (1) and (2)

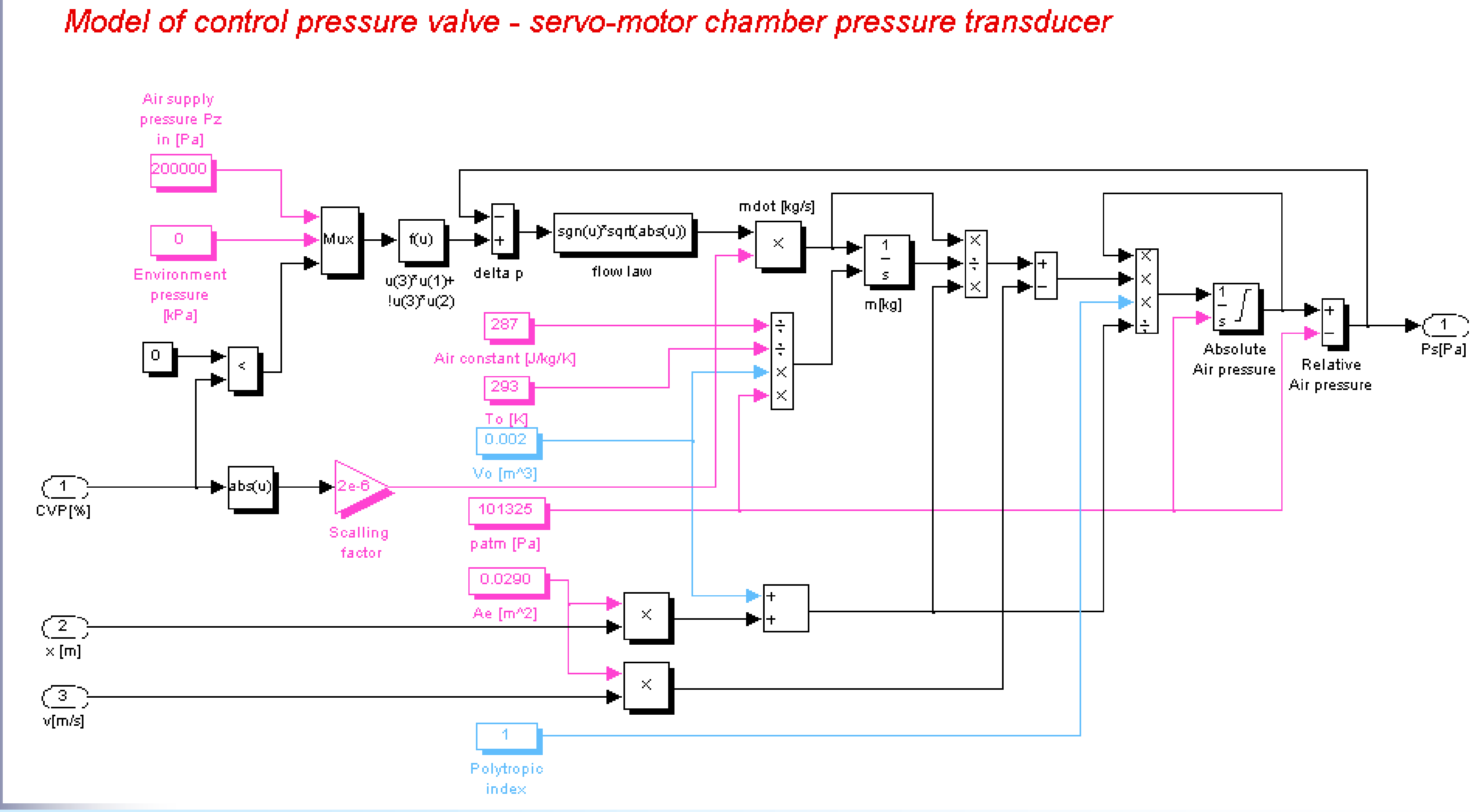
$$\dot{p} = \frac{1}{\left[\dfrac{np}{\rho V}\right]}\left(\dot{m} - \rho \dot{V}\right) \qquad (3)$$

Assumming isothermal evolution and n=1

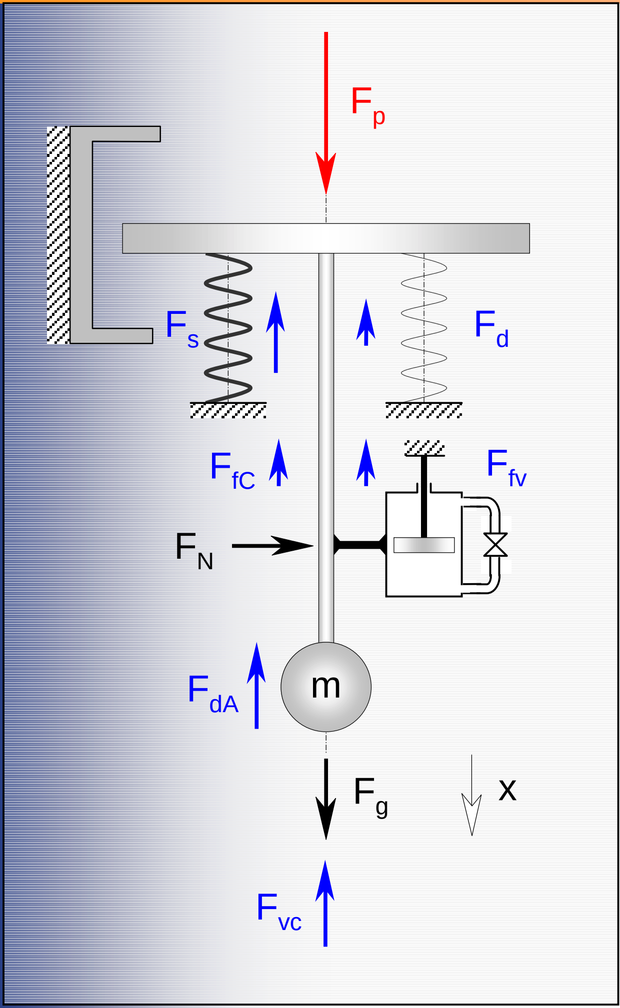
$$p = \frac{1}{\left[\dfrac{RT_0}{V}\right]}\int_0^t \dot{m} - \rho \dot{V}\, dt \qquad (4)$$

Pneumatic chamber model

Simulation model



Pneumatic diaphragm servomotor model



$$F_p = p_s A_e$$

$$F_s = k_s(x + x_0)$$

$$F_d = k_d(x + x_0)$$

$$F_{fC} = \mathrm{sgn}(\dot{x}) F_N \mu_f$$

$$F_{fv} = k_v \dot{x}$$

$$F_{dA} = m\ddot{x}$$

$$F_{vc} = f(x, P1, P2, F, Kv, \alpha, \rho)$$

$$\sum_{i=1}^{n} F_i = 0$$

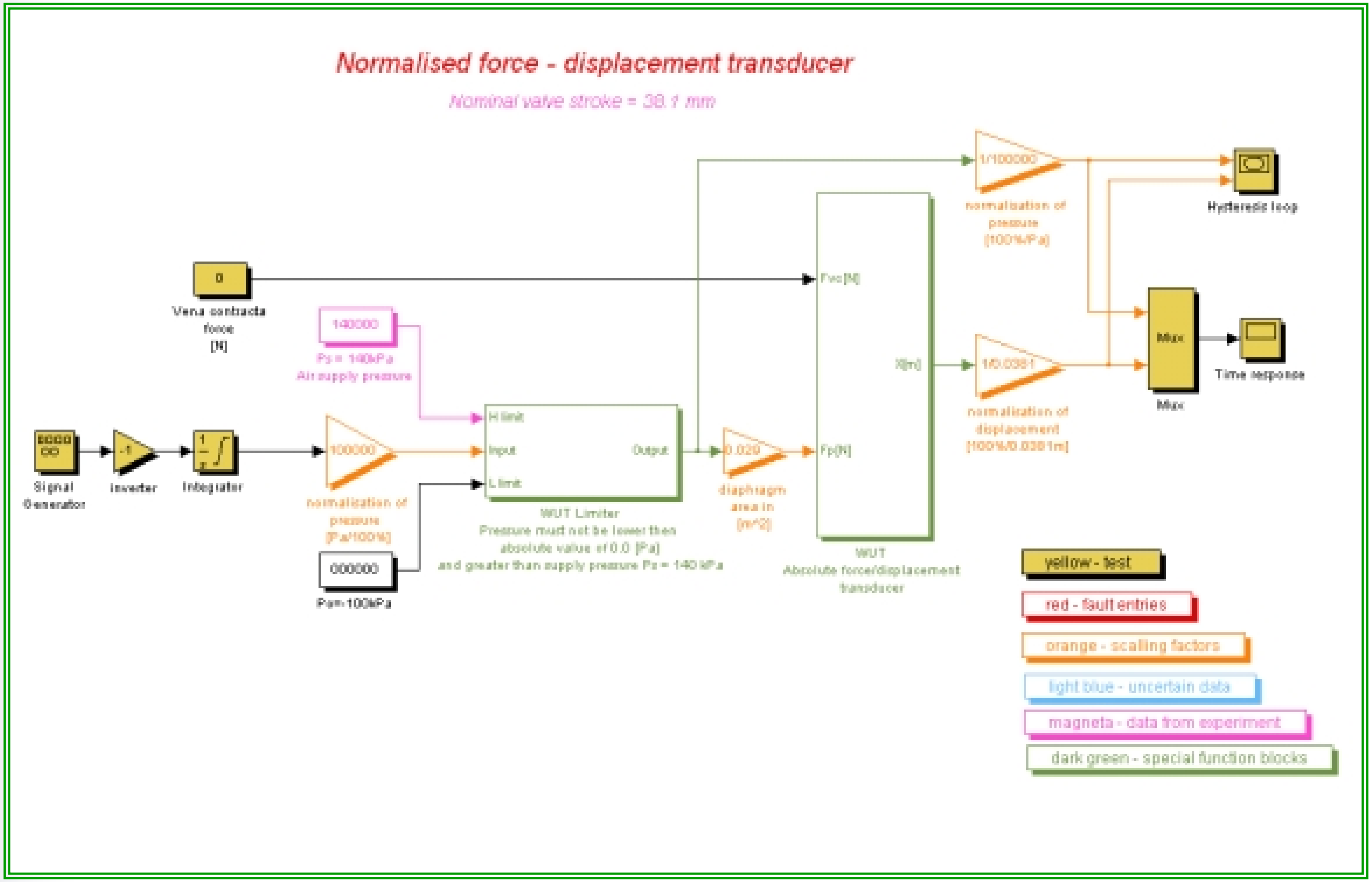
$$k_s >> k_d$$

$$m\ddot{x} + k_v\dot{x} + sign(\dot{x})F_N\mu + (k_s + k_d)x + F_{vc}(x) + (k_s + k_d)x_0 - mg = p_s A_e$$

Force balance equation

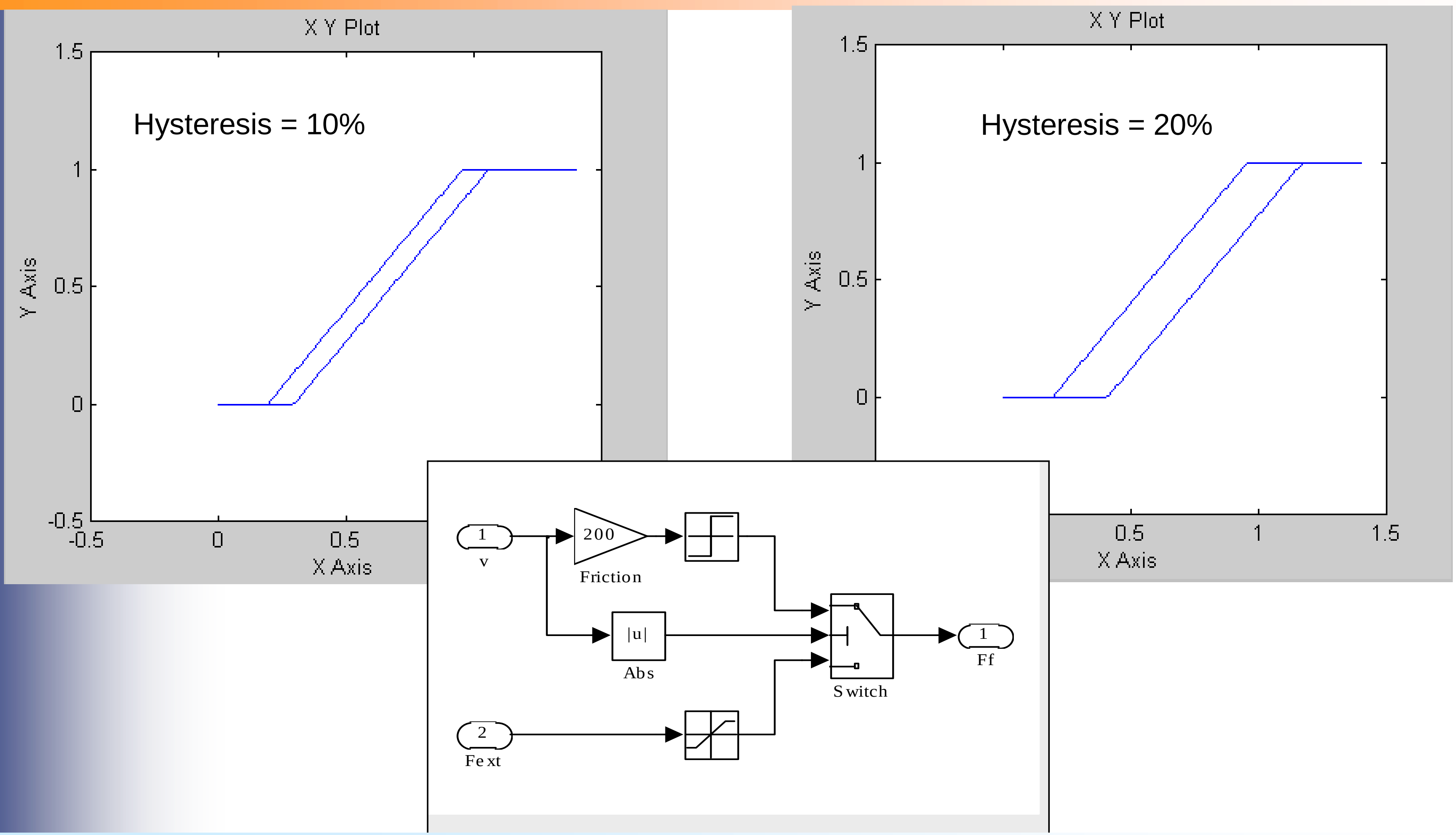
Pneumatic diaphragm servo-motor

(simulation model)

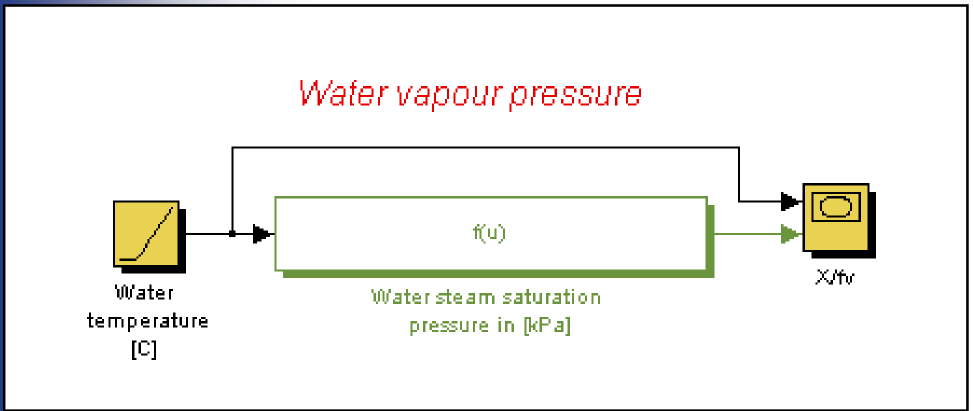


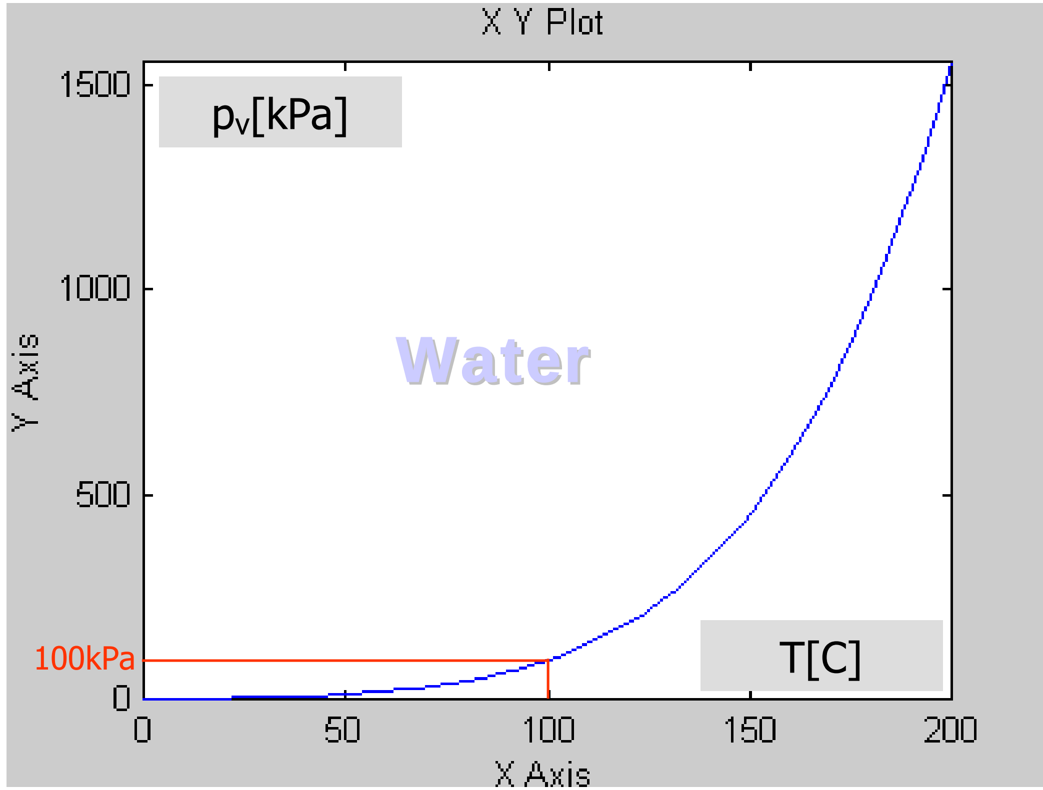
Pneumatic diaphragm servo-motor

(Model of stick-slip effect)



Vapor pressure law





$$\log p_v = -\frac{a}{T} + b$$

Approximation of water vapor pressure - temperature function

Water vapor pressure versus temperature

Choked flow

When the fluid pressure in the cross sectional area of flow stream drops below the vapor pressure, the Bernoulli's law is no more valid. The choked flow occurs. Flow is no more dependent on pressure drop.

Bernoulli's flow law

$$Q = K_v \sqrt{\frac{\Delta p}{\delta}}$$

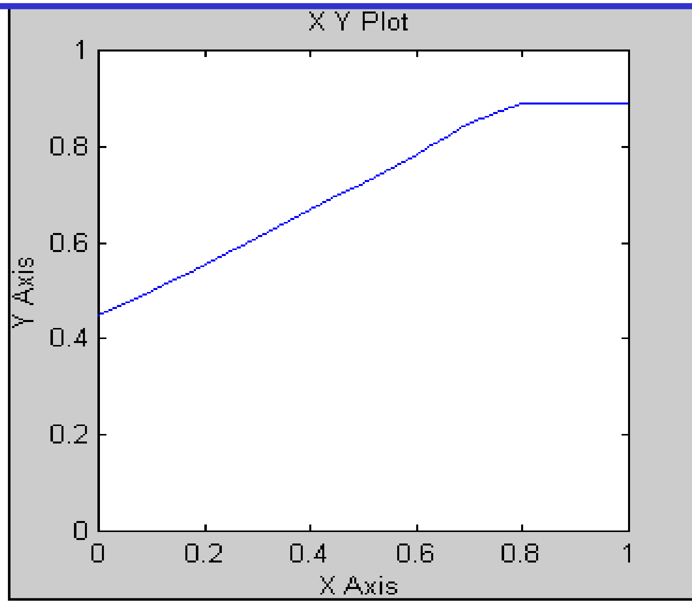
Choked flow

$$Q = K_v \sqrt{\frac{\Delta p_{all}}{\delta}}$$

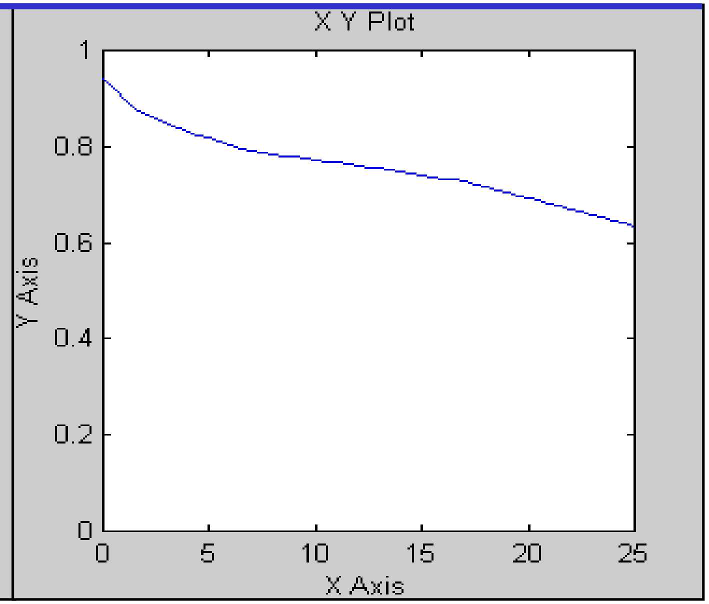
where:

$$\Delta p_{all} = K_m (P_1 - r_c p_v)$$

K_m - valve recovery coefficient
r_c - critical pressure ratio of the fluid
p_v - vapour pressure of the liquid

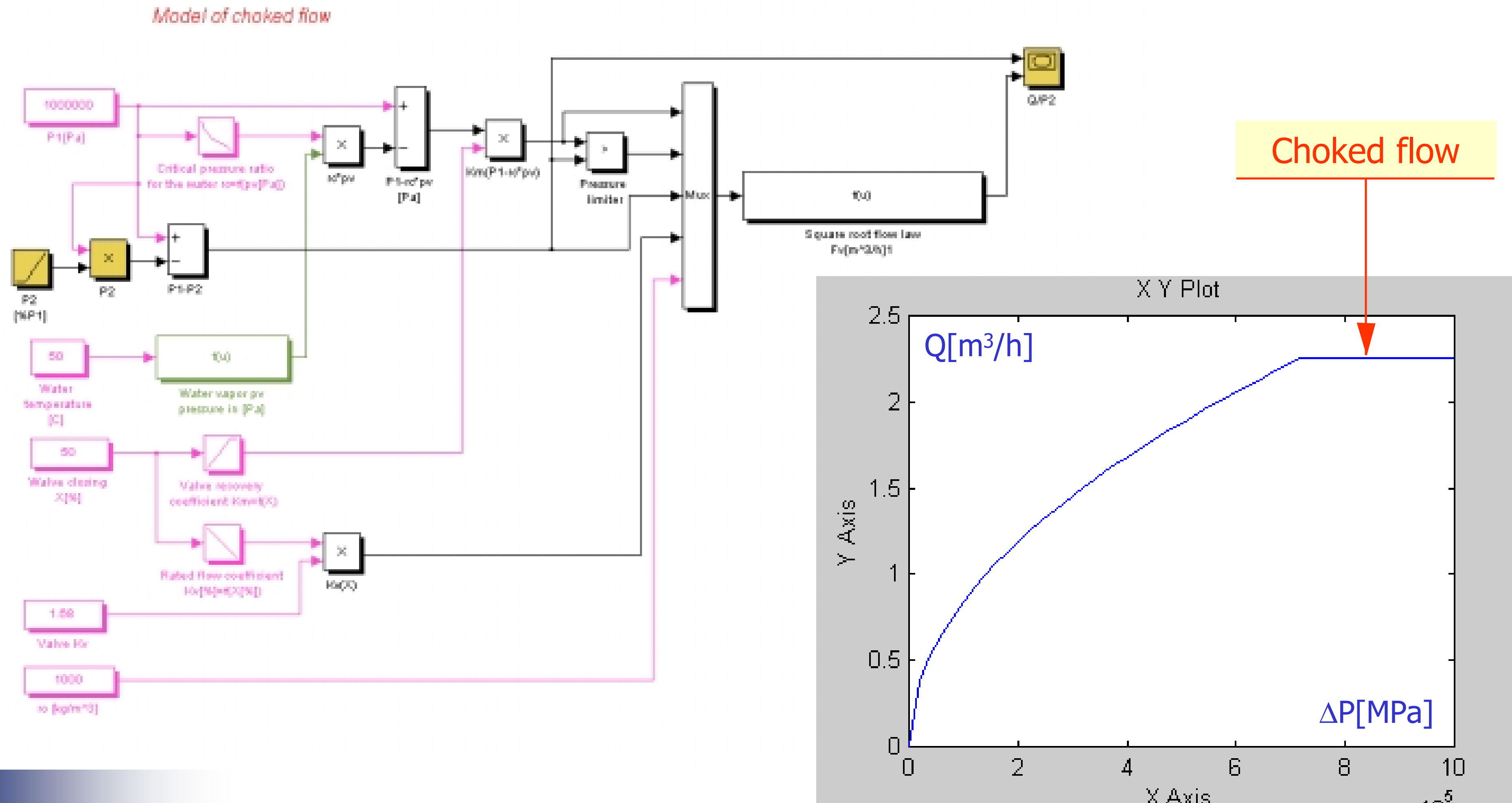


K_m curve for typical high recovery valve

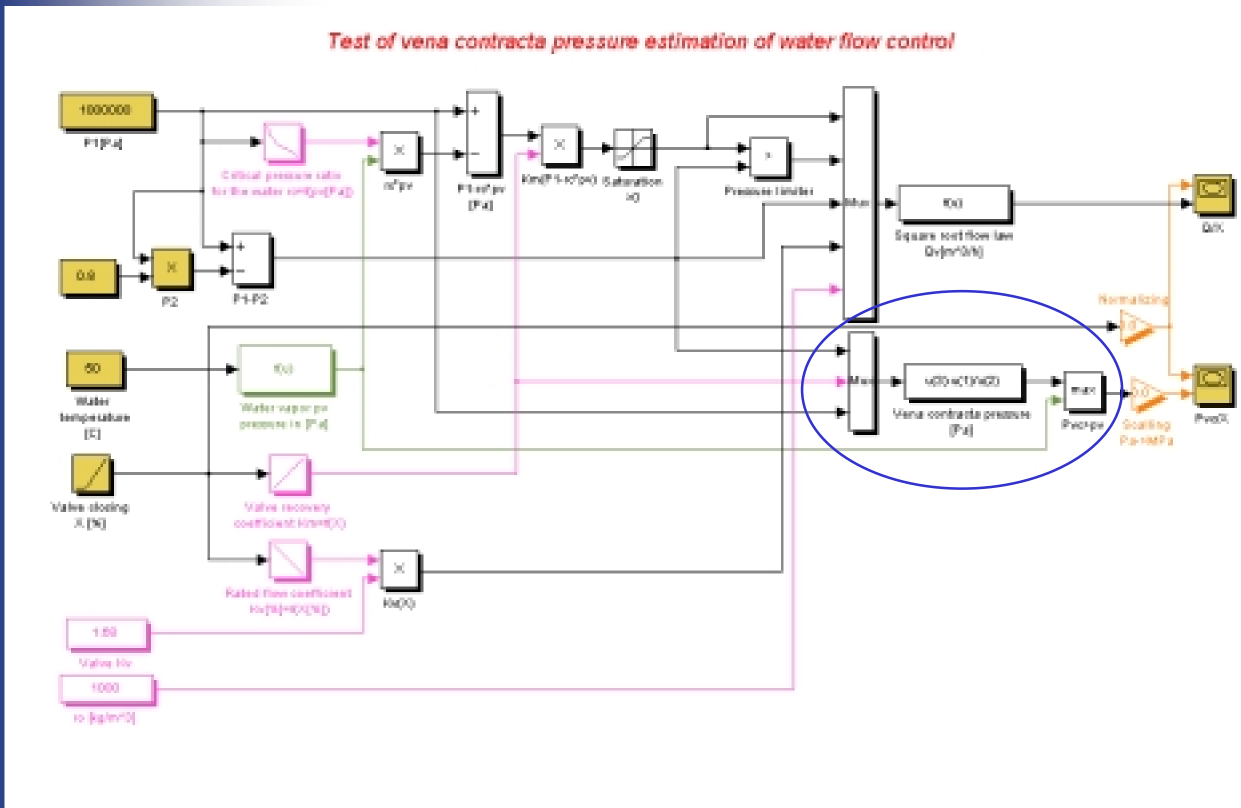


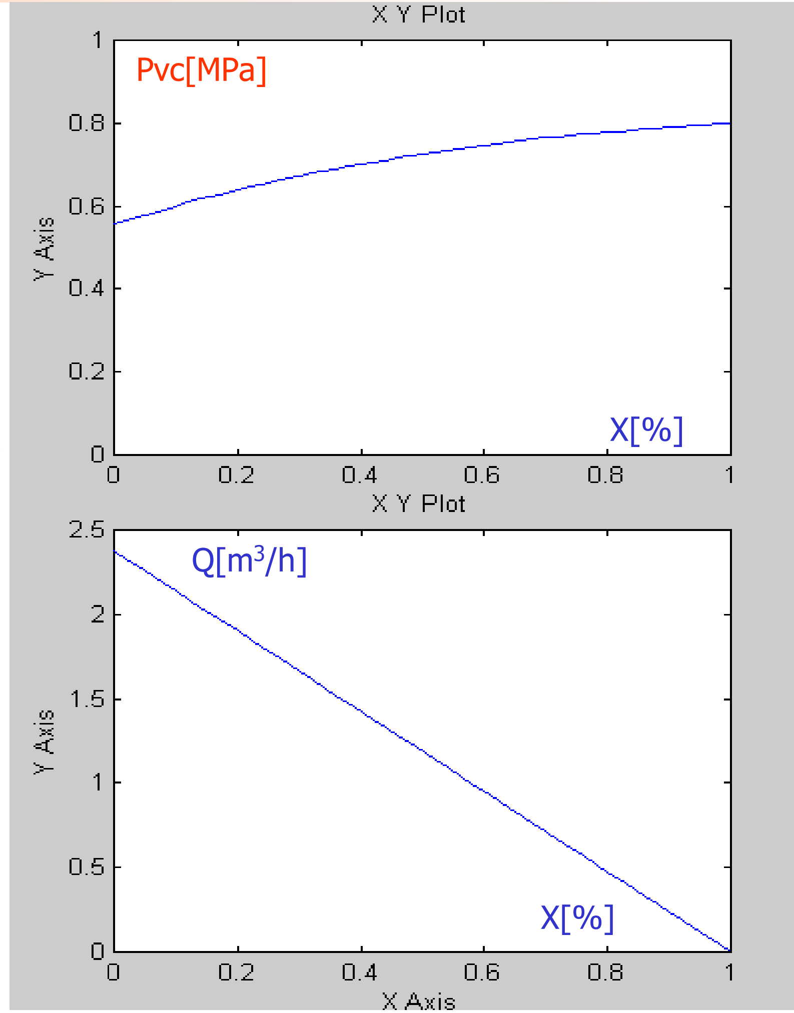
r_c critical pressure ratio for water(pressure in [MPa])

Choked flow simulations model

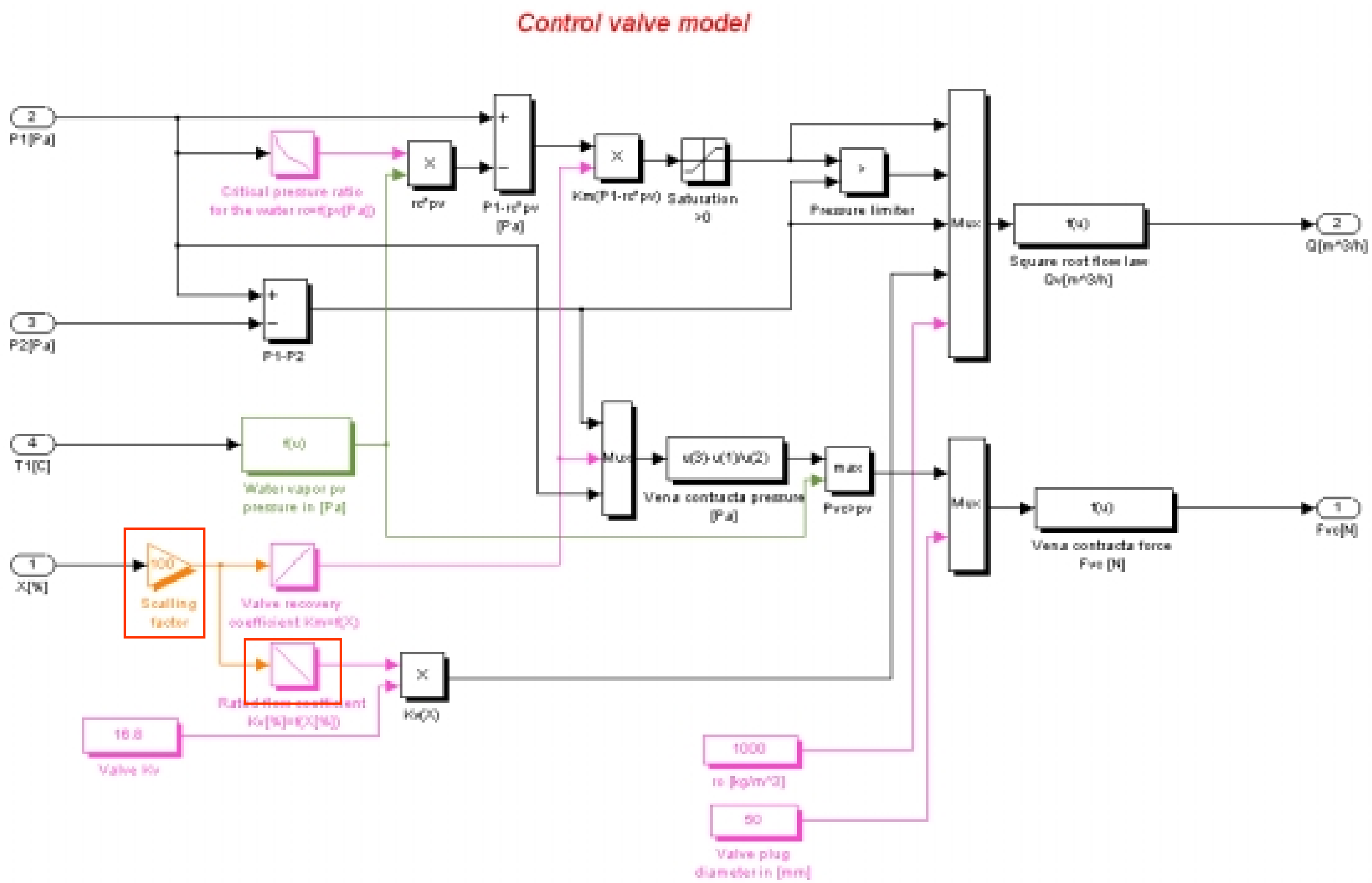


Vena contracta pressure estimation





Control valve simulation model



End remarks

- Presented Simulink actuator simulation model may be used for FDI requirements, however for common use should be provided with appropriate user friendly interface
- To fulfill this requirement the DAMADICS BENCHMARK ACTUATOR LIBRARY draft proposal was developed
- The model is based on physical laws that are are more convenient for fault simulation effects compared to abstractive ones
- The model may be used in free phase of FDI methods verification and development