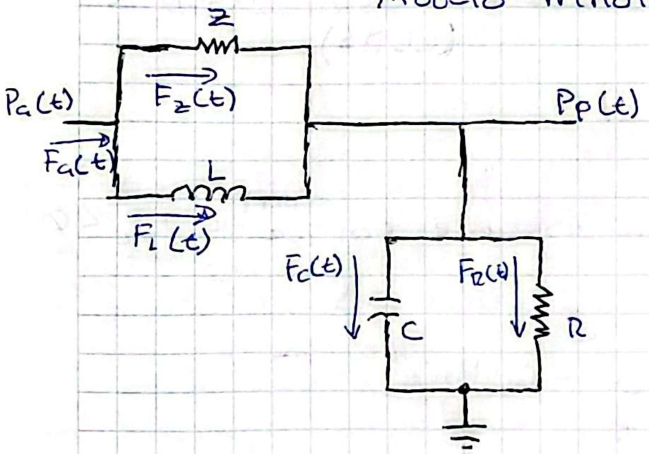
10-10-2025

Práctica: Sistema Cardiovascular 5.4

Modelo Windkessel



Ecuación principal

$$F_a(t) = F_Z(t) + F_L(t) = F_c(t) + F_R(t)$$

$$F_Z(t) = \frac{P_a(t) - P_p(t)}{Z} \qquad F_c(t) = \frac{C\,dP_p(t)}{dt}$$

$$F_L(t) = \frac{1}{L}\int [P_a(t) - P_p(t)]\,dt$$

$$F_R(t) = \frac{P_p(t)}{R}$$

Procedimiento Algebraico

$$\frac{P_a(t)}{Z} - \frac{P_p(t)}{Z} + \frac{1}{L}\int [P_a(t) - P_p(t)]\,dt = \frac{C\,dP_p(t)}{dt} + \frac{P_p(t)}{R}$$

$$\frac{P_a(s)}{Z} - \frac{P_p(s)}{Z} + \frac{P_a(s) - P_p(s)}{Ls} = Cs\,P_p(s) + \frac{P_p(s)}{R}$$

$$\left(\frac{1}{Z} + \frac{1}{Ls}\right) P_a(s) = \left(Cs + \frac{1}{R} + \frac{1}{Z} + \frac{1}{Ls}\right) P_p(s) = \frac{R(Z+Ls) + LsZ(CRs+1)}{RLsZ}$$

$$\frac{Ls+Z}{LZs}\,P_a(s) = \frac{CRLs^2 + LZs + RLs + RZ}{RLZs}\,P_p(s)$$

$$\frac{P_p(s)}{P_a(s)} = \cancel{\frac{\frac{Ls+Z}{LZs}}{\frac{CRLs^2 + LZs + RLs + RZ}{RLZs}}} = \frac{\frac{Ls+Z}{LZs}}{\frac{R(Z+Ls) + LsZ(CRs+1)}{RLsZ}}$$

$$\frac{P_p(s)}{P_a(s)} = \frac{RLs + RZ}{CLRZs^2 + (LZ + RL)s + RZ} \quad \Bigg\} \text{ Función de transferencia}$$

ERROR en el estado Estacionario:

$$e(s) = \lim_{s \to 0} s\,P_a(s)\left[1 - \frac{P_p(s)}{P_a(s)}\right] = \lim_{s \to 0} s \cdot \frac{1}{s}\left[1 - \frac{R\cancel{Ls}^{\,0} + RZ}{CL\cancel{RZs^2}^{\,0} + (LZ+RL)s + RZ}\right]$$

$$e(s) = 1 - \frac{RZ}{RZ} = 0\,V$$

Estabilidad en lazo abierto

$$\lambda_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \qquad \lambda_{1,2} = \frac{-(LZ+RL) \pm \sqrt{(LZ+RL)^2 - 4(CLRZ)(RZ)}}{2(CLRZ)}$$

$a = CLRZ$
$b = LZ + RL$
$c = RZ$

$$\lambda_{1,2} = \frac{(-)(\quad)}{+}$$

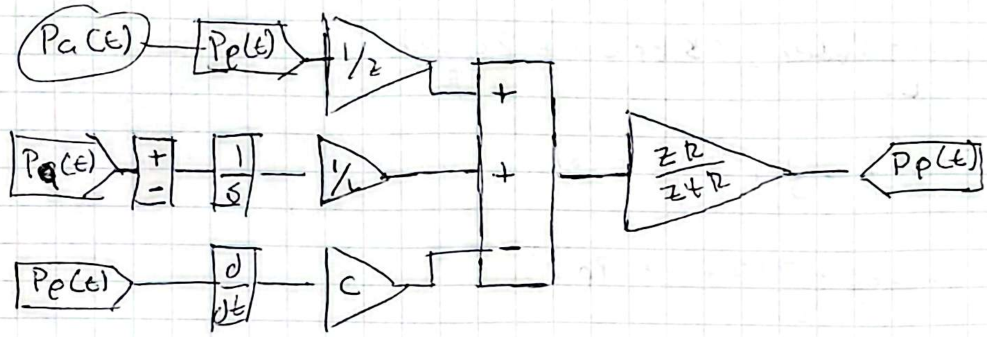
∴ El sistema tiene una respuesta estable porque $\boxed{Re\,\lambda_{1,2} < \varnothing}$

→ Modelo de ecuaciones integro-diferenciales

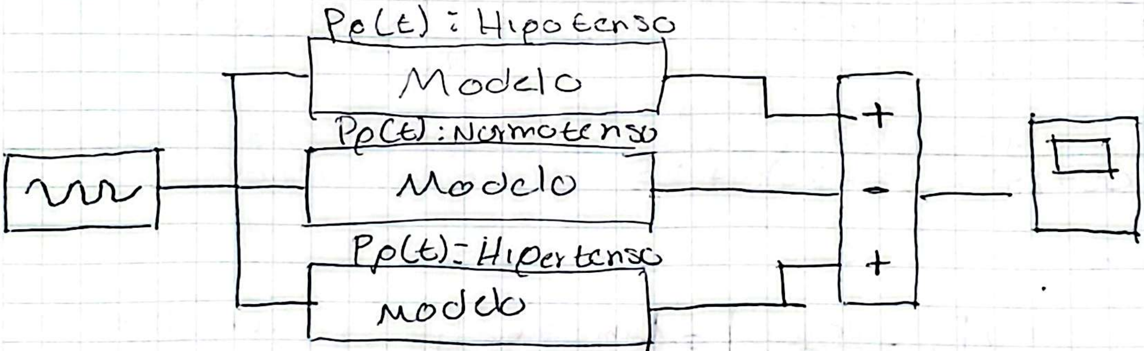
$$P_p(t)\left(\frac{1}{R} + \frac{1}{Z}\right) = \frac{P_a(t)}{Z} + \frac{1}{L}\int [P_a(t) - P_p(t)]\,dt - \frac{C\,dP_p(t)}{dt}$$

$$P_p(t) = \left(\frac{P_a(t)}{Z} + \frac{1}{L}\int [P_a(t) - P_p(t)]\,dt - \frac{C\,dP_p(t)}{dt}\right)\frac{ZR}{Z+R}$$

Diagrama de bloques



Modelo en simulink (Lazo Abierto)



Min: -0.2
max: 1
seed: 106

Respuesta Estable