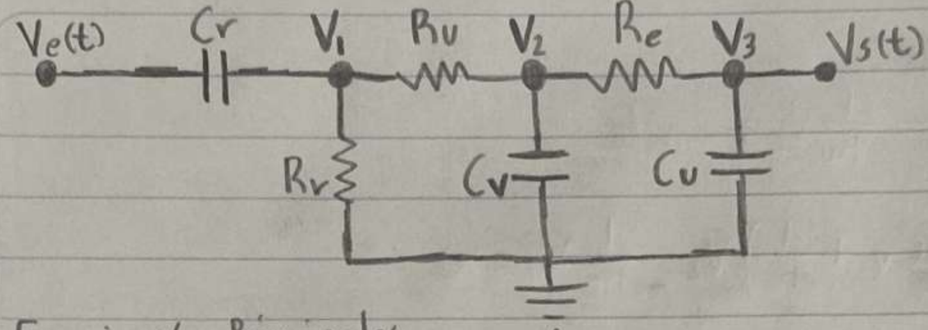


Ecuaciones Principales

Nodo 1: $C_r \frac{d}{dt}(V_1 - V_e) + \frac{V_1}{R_e} + \frac{V_1 - V_2}{R_u} = 0$

Nodo 2: $\frac{V_2 - V_1}{R_u} + C_v \frac{dV_2}{dt} + \frac{V_2 - V_3}{R_e} = 0$

Nodo 3: $\frac{V_3 - V_2}{R_e} + C_u \frac{dV_3}{dt} = 0$

Transformada de Laplace

Nodo 1: $sC_r(V_1 - V_2) + \frac{V_1}{R_r} + \frac{V_1 - V_2}{R_u} = 0$

Nodo 2: $\frac{V_2 - V_1}{R_u} + sC_vV_2 + \frac{V_2 - V_3}{R_e} = 0$

Nodo 3: $\frac{V_3 - V_2}{R_e} + sC_uV_3$

Procedimiento algebraico:

(1) $\left(sC_r+\frac{1}{R_r}+\frac{1}{R_v}\right)V_1-\frac{1}{R_v}V_2=sC_rV_e$

(2) $-\frac{1}{R_v}V_1+\left(\frac{1}{R_v}+sC_v+\frac{1}{R_e}\right)V_2-\frac{1}{R_e}V_3=0$

(3) $-\frac{1}{R_e}V_2+\left(\frac{1}{R_e}+sC_v\right)V_3=0$

(3) $\times\ R_e=-V_2+(1+sC_vR_e)V_3=0$

$$\underline{V_2=(1+sC_vR_e)V_3}$$

(2) $-\frac{1}{R_v}V_1+\left(\frac{1}{R_v}+sC_v+\frac{1}{R_e}\right)(1+sC_vR_e)V_3-\frac{1}{R_e}V_3=0$

$$\alpha(s)=\left(\frac{1}{R_v}+sC_v+\frac{1}{R_e}\right)(1+sC_vR_e)-\frac{1}{R_e}$$

$-\frac{1}{R_v}V_1+\alpha(s)V_3=0$

$\underline{V_1=R_v\,\alpha(s)V_3}$

(1) $\left(sC_r+\frac{1}{R_r}+\frac{1}{R_v}\right)(R_v\,\alpha(s)V_3)-\frac{1}{R_v}(1+sC_vR_e)V_3=sC_rV_e$

$V_3\left[R_v\left(sC_r+\frac{1}{R_r}+\frac{1}{R_v}\right)\alpha(s)-\frac{1}{R_v}(1+sC_vR_e)\right]=sC_rV_e$

$$\frac{V_3(s)}{V_e(s)}=\frac{sC_r}{D(s)}$$

$$D(s)=R_v\left(sC_r+\frac{1}{R_r}+\frac{1}{R_v}\right)\alpha(s)-\frac{1}{R_v}(1+sC_vR_e)$$

$a = \frac{1}{R_v}$ $\quad b = \frac{1}{R_r}$ $\quad c = \frac{1}{R_e}$

$$\alpha(s) = (a + s(C_v + c)(1 + s(C_u R_e) - c$$
$$= (a+c) + (a+C)sC_uR_e + sC_v + s^2 C_vC_uR_e - c$$
$$= a + s((a+c)C_uR_e + C_v) + s^2(C_vC_uR_e)$$

$q_0 = a$ $\quad q_1 = (a+c)C_uR_e + C_v$ $\quad q_2 = C_vC_uR_e$

$$P(s) = R_v\left(sC_r + \frac{1}{R_r} + \frac{1}{R_v}\right) = R_v sC_r + \frac{R_v}{R_r} + 1$$

$p_1 = R_vC_r$ $\quad p_0 = \frac{R_v}{R_r} + 1$

$$\alpha(s) = q_0 + q_1 s + q_2 s^2$$

$$P(s) = p_1 s + p_0$$

$$D(s) = P(s) \cdot \alpha(s) - a(1 + sC_uR_e)$$

$$D(s) = (p_0 + p_1 s)(q_0 + q_1 s + q_2 s^2) - a(1 + sC_uR_e)$$
$$= p_0q_0 + s(p_0q_1 + p_1q_0) + s^2(p_0q_2 + p_1q_1) + s^3(p_1q_2) - a - asC_uR_e$$
$$= p_0q_0 - a + s(p_0q_1 + p_1q_0 - aC_uR_e) + s^2(p_0q_2 + p_1q_1) + s^3(p_1q_2)$$

$(s^0)\ p_0 q_0 - a = \left(\frac{\cancel{R_u}}{R_r} + 1\right)\frac{1}{\cancel{R_u}} - \frac{1}{\cancel{R_u}} = \frac{1}{R_r}$

$(s)\ p_0 q_1 + p_1 q_0 - a C_u R_e =$

$q_1 = C_u R_e\left(\frac{1}{R_u} + \frac{1}{R_e}\right) + C_v = C_u \frac{R_e}{R_u} + C_u + C_v$

$p_0 q_1 = \left(\frac{R_u}{R_r} + 1\right)\left(C_u \frac{R_e}{R_u} + C_u + C_v\right)$

$= C_u \frac{R_e}{R_r} + C_u \frac{R_u}{R_r} + C_v \frac{R_u}{R_r} + C_u \frac{R_e}{R_u} + C_u + C_v$

$p_1 q_0 = \cancel{R_u} C_r \cdot \frac{1}{\cancel{R_u}} = C_r$

$a C_u R_e = C_u \frac{R_e}{R_u}$

$p_0 q_1 + p_1 q_0 - a C_u R_e = C_u \frac{R_e}{R_r} + C_u \frac{R_u}{R_r} + C_v \frac{R_u}{R_r} + \cancel{C_u \frac{R_e}{R_u}} + C_u + C_v + C_r - \cancel{C_u \frac{R_e}{R_u}}$

$= C_u \frac{R_e}{R_r} + C_u \frac{R_u}{R_r} + C_v \frac{R_u}{R_r} + C_u + C_v + C_r$

$(s^2)\ p_0 q_2 + p_1 q_1 = \left(\frac{R_u}{R_r} + 1\right)(C_v C_u R_e) + R_u C_r\left(C_u \frac{R_e}{R_u} + C_u + C_v\right)$

$p_0 q_2 = \frac{R_u}{R_r} C_v C_u R_e + C_v C_u R_e$

$p_1 q_1 = \cancel{R_u} C_r C_u \frac{R_e}{\cancel{R_u}} + R_u C_r C_u + R_u C_r C_v$

$= C_r C_u R_e + R_u C_r C_u + R_u C_r C_v$

$p_0 q_2 + p_1 q_1 = \frac{R_u}{R_r} C_v C_u R_e + C_v C_u R_e + C_r C_u R_e + C_r C_u R_u + C_r C_v R_u$

$$(s^3)\quad p_1 q_2 = (R_u C_r)(C_v C_u R_e) = \boxed{C_r C_v C_u R_e R_u}$$

$$D(s) = (C_r C_v C_u R_e R_u)s^3 + \left(C_v C_u R_e \frac{R_u}{R_r} + C_v C_u R_e + C_r C_u R_e + C_r C_u R_u + \ldots\right.$$

$$\ldots \left. + C_r C_v R_u\right)s^2 + \left(C_u \frac{R_e}{R_r} + C_u \frac{R_u}{R_r} + C_v \frac{R_u}{R_r} + C_u + C_v + C_r\right)s + \frac{1}{R_r}$$

$$H(s) = \frac{V_3(s)}{V_e(s)} = \frac{sC_r}{D(s)} \cdot \left(\frac{R_r}{R_r}\right)$$

$$D(s) \cdot R_r = (C_r C_v C_u R_e R_u R_r)s^3 + (C_v C_u R_e R_u + C_v C_u R_e R_r + C_r C_u R_e R_r + \ldots$$

$$\ldots + C_r C_u R_u R_r + C_r C_v R_u R_r)s^2 + (C_u R_e + C_u R_u + C_v R_u + C_u R_r + C_v R_r + \ldots$$

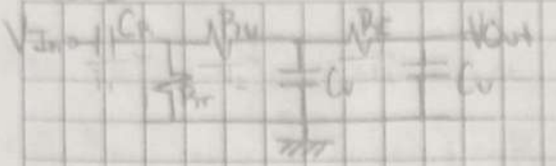
$$\ldots + C_r R_r)s + 1$$

$$\boxed{H(s) = \frac{V_3(s)}{V_e(s)} = \frac{(C_r R_r)s}{(C_r C_v C_u R_e R_u R_r)s^3 + (C_v C_u R_e R_u + C_v C_u R_e R_r + C_r C_u R_e R_r + \ldots + C_r C_u R_u R_r + C_r C_v R_u R_r)s^2 + (C_u R_e + C_u R_u + C_v R_u + C_u R_r + \ldots + C_v R_r - C_r R_r)s + 1}}$$

Error estado estacionario.

$$e(s) = \lim_{s \to 0} \left[1 - \frac{V_3}{V_e}\right] = \left[1 - \frac{0}{0+0+0+1}\right] = 1$$

Fase 1



C_r: Capacitor riñón
R_r: Resistencia riñón
R_u: " uréteres

Valores no cambian

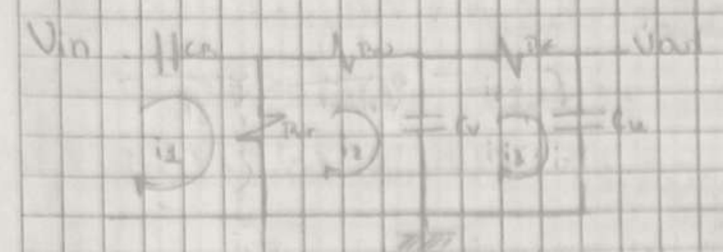
$\downarrow C_v$: Capacitor vejiga
$\downarrow R_E$: Esfínter
C_u: Capacitor uretra

Valores disminuyen en caso de incontinencia

Control: paciente sano
Caso: paciente con incontinencia por esfuerzo
- vejiga rígida

Fase 2.

Función de transferencia, error en estado estacionario, modelo de ecuaciones, estabilidad en lazo abierto (control y caso) + Simulink



$V_{in} \Rightarrow V_e$
$V_{out} \Rightarrow V_s$

$$V_e(t) = \frac{1}{C_r}\int i_1(t)\,dt + R_r[i_1(t) - i_2(t)] \quad \text{---}(1)$$
$$R_r[i_1(t) - i_2(t)] = R_u[i_2(t)] + \frac{1}{C_v}\int[i_2(t) - i_3(t)]\,dt \quad \text{---}(2)$$
$$\frac{1}{C_v}\int[i_2(t) - i_3(t)]\,dt = R_E[i_3(t)] + \frac{1}{C_u}\int i_3(t)\,dt \quad \text{---}(3)$$
$$V_s(t) = \frac{1}{C_u}\int i_3(t)\,dt \quad \text{---}(4)$$

ecuaciones principales

① $V_e(t) = \frac{1}{C_r}\int i_1(t)\,dt + R_r i_1(t) - R_r i_2(t)$
② $R_r i_1(t) - R_r i_2(t) = R_u i_2(t) + \frac{1}{C_v}\int[i_2(t) - i_3(t)]\,dt$
③ $\frac{1}{C_v}\int[i_2(t) - i_3(t)]\,dt = R_E i_3(t) + \frac{1}{C_u}\int i_3(t)\,dt$
④ $V_s(t) = \frac{1}{C_u}\int i_3(t)\,dt$

→① $i_1(t) = \left[V_e(t) - \frac{1}{C_r}\int i_1(t)\,dt + R_r i_2(t)\right]\left[\frac{1}{R_r}\right]$

$R_u i_2(t) + R_r i_2(t) = R_r i_1(t) - \frac{1}{C_v}\int[i_2(t) - i_3(t)]\,dt$
$i_2(t)[R_u + R_r] = R_r i_1(t) - \frac{1}{C_v}\int[i_2(t) - i_3(t)]\,dt$

→② $i_2(t) = \left\{R_r i_1(t) - \frac{1}{C_v}\int[i_2(t) - i_3(t)]\,dt\right\}\left[\frac{1}{R_u + R_r}\right]$

$R_E i_3(t) = \frac{1}{C_v}\int[i_2(t) - i_3(t)]\,dt - \frac{1}{C_u}\int i_3(t)\,dt$

→③ $i_3(t) = \left\{\frac{1}{C_v}\int[i_2(t) - i_3(t)]\,dt - \frac{1}{C_u}\int i_3(t)\,dt\right\}\left[\frac{1}{R_E}\right]$

→④ $V_s(t) = \frac{1}{C_u}\int i_3(t)\,dt$

modelo de ecuaciones integro-diferenciales