(9.)

$$F(t) \longrightarrow \boxed{\text{Cantilever}} \xrightarrow{x(t)} \boxed{\text{Sensor}} \longrightarrow v(t)$$

$K_1 \cdot G_c(s)$ $\quad$ K_2

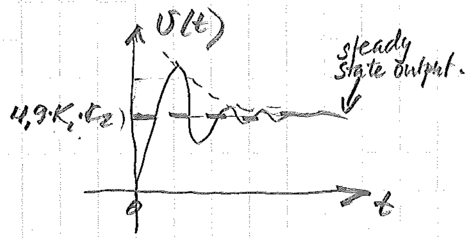
$$V(s) = K_1 \cdot K_2 \cdot G_c(s) \cdot F(s)$$

a) step input of $F = m \cdot g = 0.5 \cdot 9.81 = 4.9\,N$

$$F(s) = 4.9 \cdot \frac{1}{s}$$

$$\Rightarrow V(s) = 4.9 \cdot K_1 \cdot K_2 \cdot G_c(s) \cdot \frac{1}{s}$$

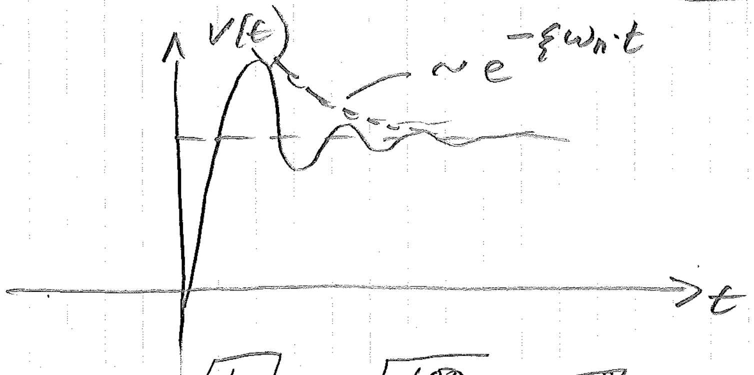
"Step-response graph"



steady state output:

$$V_{ss}(t) = 4.9 \cdot K_1 \cdot K_2$$
$$= 4.9 \cdot \frac{1}{k} \cdot K_2 = 4.9 \cdot \frac{1}{100} \cdot 10 = \underline{0{,}49\,V}$$

b)



unit step response

$$- \omega_n = \sqrt{\frac{k}{m}} = \sqrt{\frac{100}{0.5}} = \sqrt{200} \approx 14{,}14\ \text{rad/s}$$

$$- \xi = \frac{\lambda}{2\sqrt{km}} = \frac{2}{2\sqrt{100 \cdot 0.5}} = \frac{1}{\sqrt{50}} \approx 0.14$$

($\xi < 1$, underdamped 2nd order system)

Unit step response:

$$v(t) = K_1 K_2 \left(1 - \underbrace{e^{-\xi\omega_n \cdot t}}_{\to 0 \text{ for steady state output}} \left(\cos(\omega_d t) + b \sin(\omega_d \cdot t)\right)\right)$$

$\to 0$ for steady state output

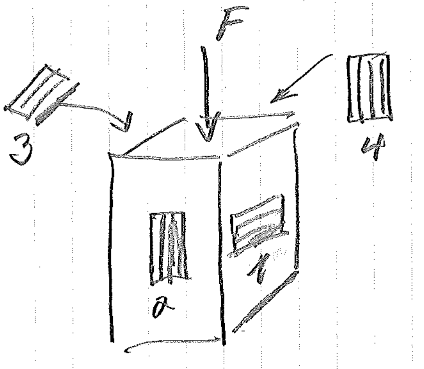
$$e^{-\xi \cdot \omega_n \cdot t} = \{\xi = 0.14,\ \omega_n = 14{,}14\} \approx e^{-2 \cdot t}$$

Time between measurement $= 0.5\,s$ (120 per minute)

$\Rightarrow e^{-\xi\omega_n \cdot 0.5} = e^{-1} = 0{,}37 \rightarrow$ No steady state is reached between measurement (not suitable!).

(10)

F

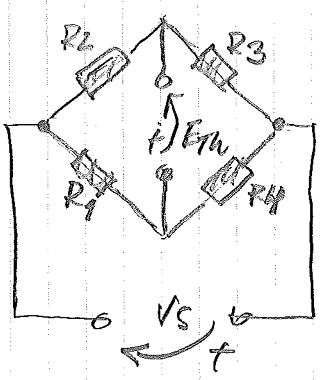


$e = \frac{\Delta l}{l} \Rightarrow \begin{cases} 2 \text{ and } 4 \text{ (compression)} : \Delta l < 0 \\ 1 \text{ and } 3 \text{ (tension)} : \Delta l > 0 \end{cases}$

$\Delta R = R_0 \cdot G \cdot e \Rightarrow \begin{cases} 2 \text{ and } 4 \quad \Delta R < 0 \quad \text{decrease } R \\ 1 \text{ and } 3 \quad \Delta R > 0 \quad \text{increase } R. \end{cases}$

---

a)



$$E_{Th} = V_S\left(\frac{R_1}{R_1+R_4} - \frac{R_2}{R_2+R_3}\right) \quad (*)$$

Accuracy: (due to temp. changes) $E_{Th} = 0$ due to change in temperature

$\Delta R_1 = \Delta R_2 = \Delta R_3 = \Delta R_4 = \Delta R \xrightarrow{(*)} E_{Th} = 0$

sensitivity: $\begin{cases} 1 = R_1 \\ 3 = R_3 \\ 2 = R_2 \\ 4 = R_4 \end{cases}$

R_1 and R_3 ↑ (tension $\Delta l > 0$)

R_2 and R_4 ↓ (compression $\Delta l < 0$)

in (*) → high sensitivity

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b) $F = 10^5\ N$

Calculate E_{Th}!

$$\begin{cases} R_1 = R_3 = R_0 + \Delta R = R_0(1 + G \cdot e_T) \\ R_2 = R_4 = R_0 + \Delta R = R_0(1 + G \cdot e_l) \end{cases}$$

$$e_l = -\frac{F}{A \cdot E} = -\frac{10^5}{0{,}1 \times 0{,}1 \times 2{,}1 \cdot 10^{11}} = -4{,}76 \cdot 10^{-5}$$

$$e_T = -\nu \cdot e_l = -0{,}29 \cdot (-4.76 \cdot 10^{-5}) = 1{,}38 \cdot 10^{-5}$$

(10) forts.

$$R_1 = R_3 = R_0(1 + G\,e_T) =$$
$$= 100(1 + 2.1 \cdot 1.38 \cdot 10^{-5}) = 100{,}0029\ \Omega$$

$$R_2 = R_4 = R_0(1 + G \cdot e_\ell)$$
$$= 100(1 + 2.1(-4.76 \cdot 10^{-5})) = 99{,}99\ \Omega$$

$\overset{(*)}{\Rightarrow}$

$$\frac{E_{Th}}{V_S} = \left(\frac{100{,}0029}{199{,}9929} - \frac{99{,}99}{199{,}9929}\right) \approx 6.45 \cdot 10^{-5}$$

and $E_{Th} = V_S \cdot 6.45 \cdot 10^{-5}\ V$

Find V_S for max output !

$$\frac{V_S}{2R_0} \leq 30\,mA \quad \text{(max gauge current)}$$

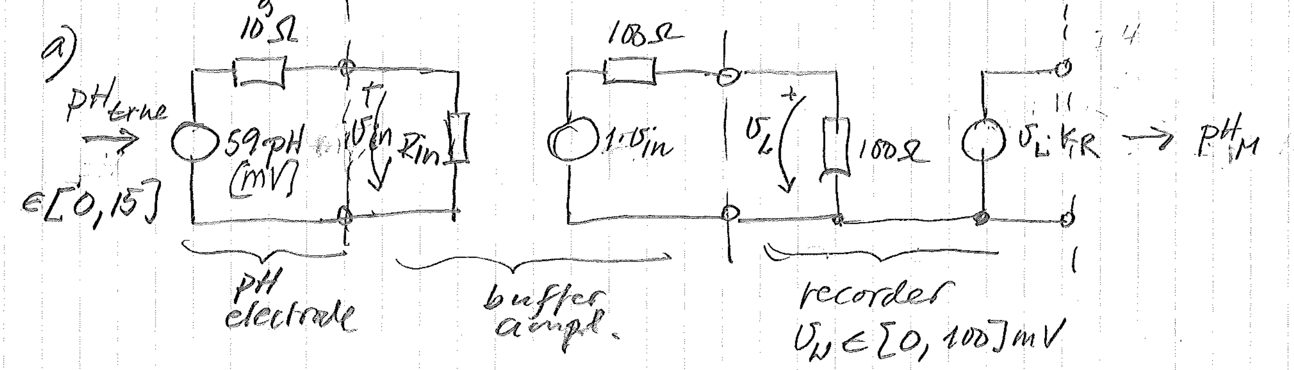
$$V_S \leq 2 \cdot R_0 \cdot 30 \cdot 10^{-3} = 2 \cdot 100 \cdot 30 \cdot 10^{-3} = 6V$$

Select $V_S = 6V$

$$\Rightarrow E_{Th} = V_S \cdot 6.45 \cdot 10^{-5} = 6 \cdot 6{,}45 \cdot 10^{-5} \approx \underline{\underline{0{,}39\ mV}}$$

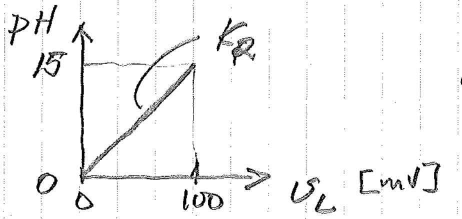
(11)

a)



b) Accurate reding: $pH_M = pH_{true}$

sensitivity recorder:



$$K_R = \frac{15-0}{100-0}\ pH/mV = 0{,}15\ pH/mV$$

$$pH_M = \overbrace{\underbrace{59 \cdot pH_{true}\left(\frac{R_{in}}{R_{in}+10^9}\right)}_{v_{in}} \cdot 1 \left(\frac{100}{100+100}\right)}^{v_L} \cdot 0.15 \qquad (*)$$

$pH_M = pH_{true}$ (accurate reading) if:

$$59\left(\frac{R_{in}}{R_{in}+10^9}\right) \cdot 1 \left(\frac{100}{100+100}\right) \cdot 0{,}15 = 1$$

$$\Rightarrow R_{in} \approx 2{,}92 \cdot 10^8\ \Omega$$

c) $\begin{cases} R_{pH} = 10^9\,\Omega \curvearrowright 2 \cdot 10^9\,\Omega \\ pH_{true} = 7 \end{cases}$

$$pH_M \underset{(*)}{=} 59 \cdot 7 \left(\frac{2.92 \cdot 10^8}{2{,}92 \cdot 10^8 + 2 \cdot 10^9}\right) \cdot 1 \cdot \frac{1}{2} \cdot 0{,}15 \approx 3{,}95$$

$$\text{Error} = pH_M - pH_{true} = 3{,}95 - 7 = -3{,}05$$

$$\%\ \text{of full scale}: \frac{-3{,}05}{15} \cdot 100\ \% \approx -20{,}3\%$$