Surname **Name** **Student's code.:**

There is no need
indeed, it is NOT allowed to use a programmable calculator!

Section 1: TRUE/FALSE QUIZZES

1. The Laplace transform of the derivative is equal to the transformed function multiplied by the Laplace abscissa s plus the value of the function in the time domain at the state 0 (initial condition)

   true ☐ false ☐

2. In a second order system the overshoot is the fractional deviation of the output from its final value, at a peak of an oscillatory step response.

   true ☐ false ☐

3. A system is BIBO stable if and only if all its poles pi have negative real parts, Re{pi} < 0.

   true ☐ false ☐

4. The integral time is the constant that divides the integral of the error signal in the PID controller

   true ☐ false ☐

Section 2: QUIZZES

1. If τ is the characteristic time of a self-regulating first order system to which an input step test is applied, the 99% of the new steady state value for the output is reached after at least:
   a. ☐ τ
   b. ☐ 3τ
   c. ☐ 5τ
   d. ☐ 7τ

2. The PID controller transfer function is

   a. ☐ $G_c=K_c[1 + \tau_D s + \tau_I s]$
   b. ☐ $G_c=K_c[1 + \tau_D s + 1/(\tau_I s)]$
   c. ☐ $G_c=K_c[1/(1+\tau_I s)+ \tau_D s]$
   d. ☐ $G_c=K_c/((\tau_{I+}\tau_D) s)$

Section 3: REFERENCE DYNAMIC MODELS

3.1. Response of a dynamic model

A thermometer with first-order time constant of 0.1 min and gain of 1.0 is in equilibrium with a liquid bath at $T_{ext_{ss}} = T_{m_{ss}} = 25°C$. At the time *t=0* min, the temperature of the bath $T_{ext}(t)$ is increased linearly at a rate of 1°C/min.

$$T_{ext}(t) = 25\ [°C] + 1\left[\frac{°C}{min}\right]\ t\ [min]$$

1. Write the forcing function $T_{ext}(t)$ in terms of deviation variable(s) $T'_{ext}(t)$.
2. Write the forcing function $T'_{ext}(t)$ in the Laplace domain ($\hat{T}_{ext}(s)$).
3. Obtain the expression, in the Laplace domain, of the measured thermometer temperature $\hat{T}_m(s)$.
4. Obtain the expression of the time evolution of the measured thermometer temperature $T_m(t)$
5. What is the difference between the measured temperature $T_m(t)$ and the bath temperature $T_{ext}(t)$ at:
   a. t = 0.1 min;
   b. t= 1.0 min.

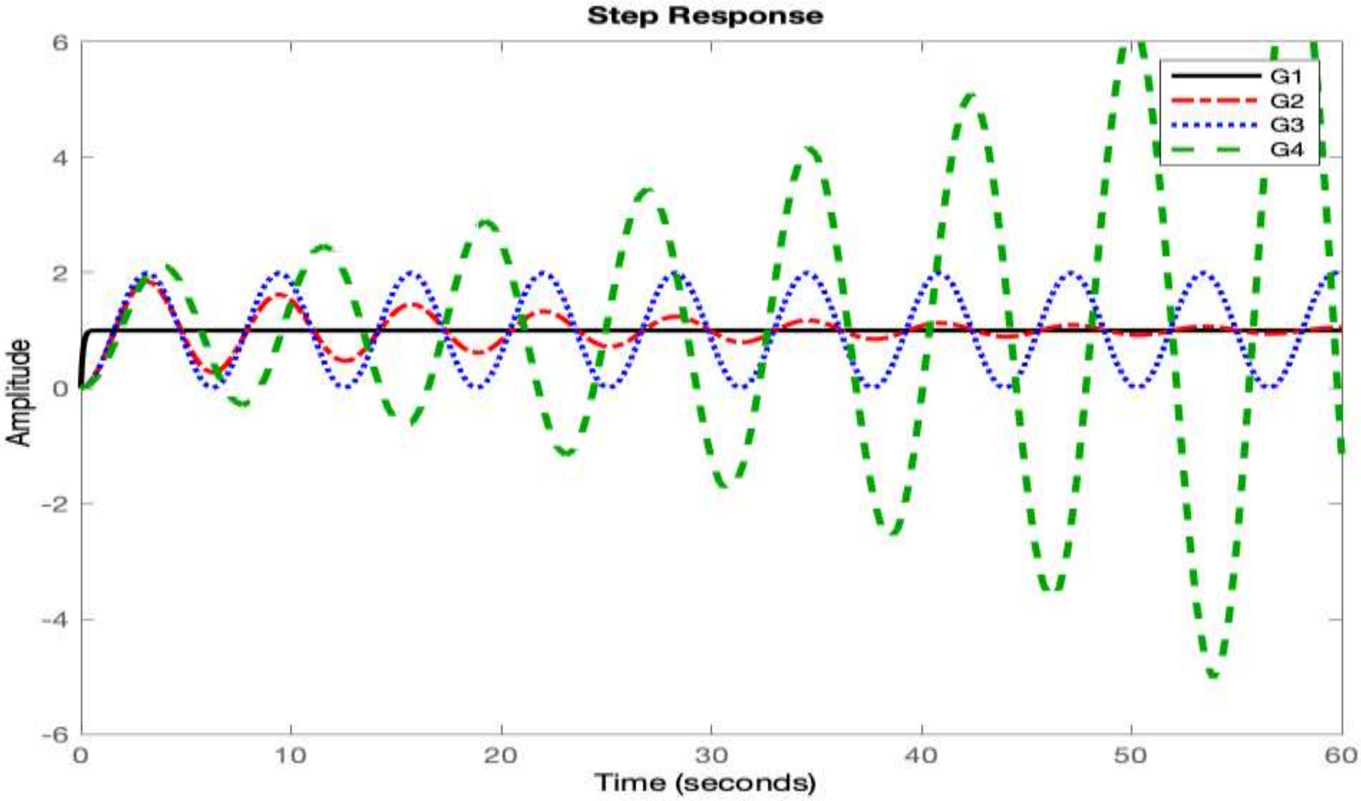
t	*exp(-t)*
0	1.00
0.25	0.78
0.5	0.60
0.75	0.47
1	0.37
1.5	0.22
2	0.14
2.5	0.08
3	0.05
3.5	0.03
4	0.02
≥ 4.5	0

Hints:

- The Laplace transform of a ramp function is: $\mathcal{L}\{t\} = 1/s^2$
- The provided table can be used to approximate the exponential decay function:

3.2 Stability of dynamic system

The diagram reports the step responses of 4 linear dynamical systems



a. provide the definition of **BIBO stability**

b. Discuss which system is BIBO stable and which one BIBO unstable,

c. try to guess qualitatively the type of transfer function for G1, G2, G3, and G4

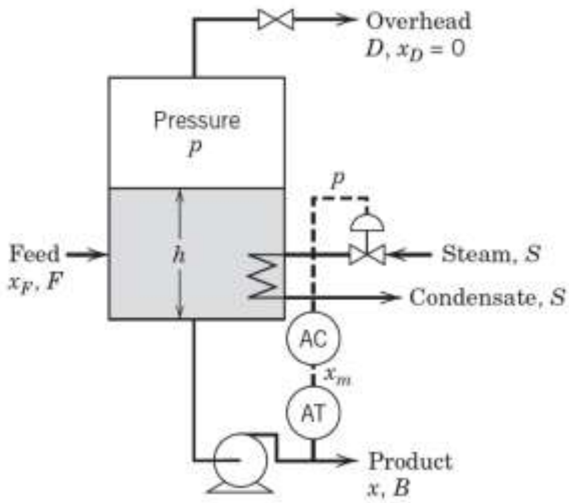
Section 4: CONTROL AND MONITORING

4.1. The feedback control

The figure shows a practical application of feedback control. In particular, a steam-heated evaporator used to concentrate a feed stream by evaporating water is shown.

Among the various process variables (flow rate, etc.)

1. select the **measured variable**
2. select the **controlled variable**
3. select the **manipulated variable**
4. select the **disturbance variable** (if any)



Among the various process **block components** (tank, valves, pump, etc.)

5. select the **sensor/measuring device**
6. select the **comparator**
7. select the **actuator**
8. select the **final control element**
9. what type of signal is used in the **control loop?**
10. what is the role of the tank in the **control loop system?**

Note**:** The symbols in the picture are reported according to the standard instrumentation symbols published by the Instrumentation, Systems and Automation (ISA) Society. "A" as first letter means "Analysis"

Section 5: CONTROLLERS

5.1 Tuning the PID controller

An unknown process is stimulated, at time 0 s, in the set-point by a step function (red dotted line in the attached figure) and, in the open loop configuration, the response of the process variable (to be controlled at closed loop) is recorded (blue solid line in the attached figure).

1. From the dynamic response determine the value of the **dead time** t_d

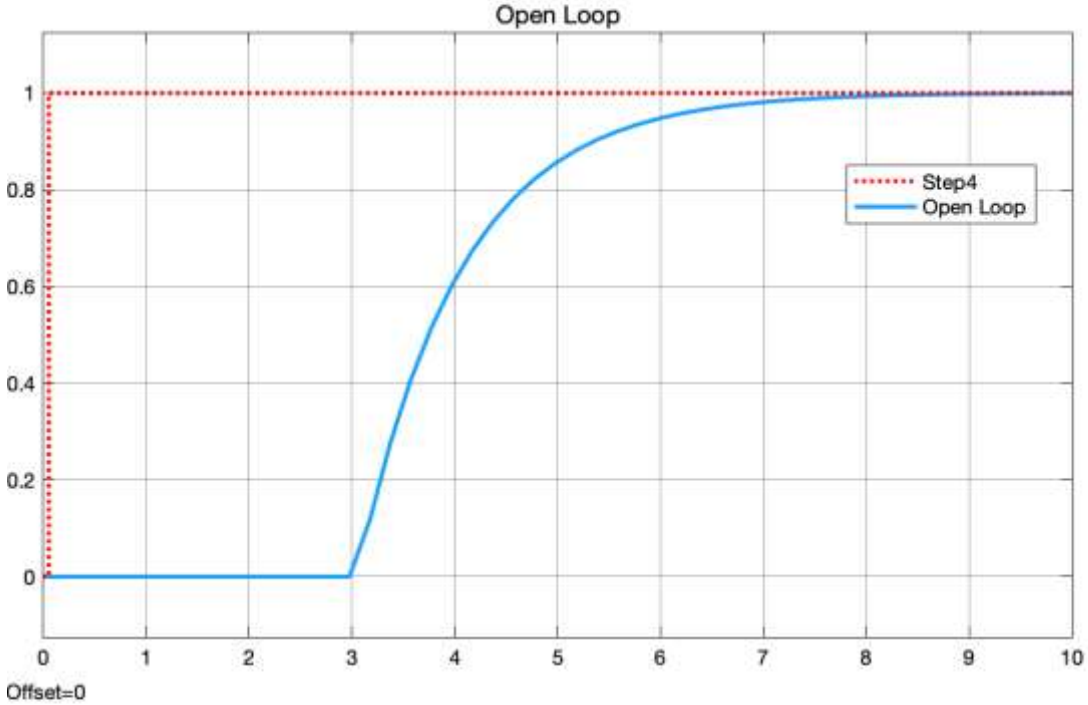
2. Obtain the transfer function of an FOPDT fitting model for which K_p=1 and τ_p=1 s;

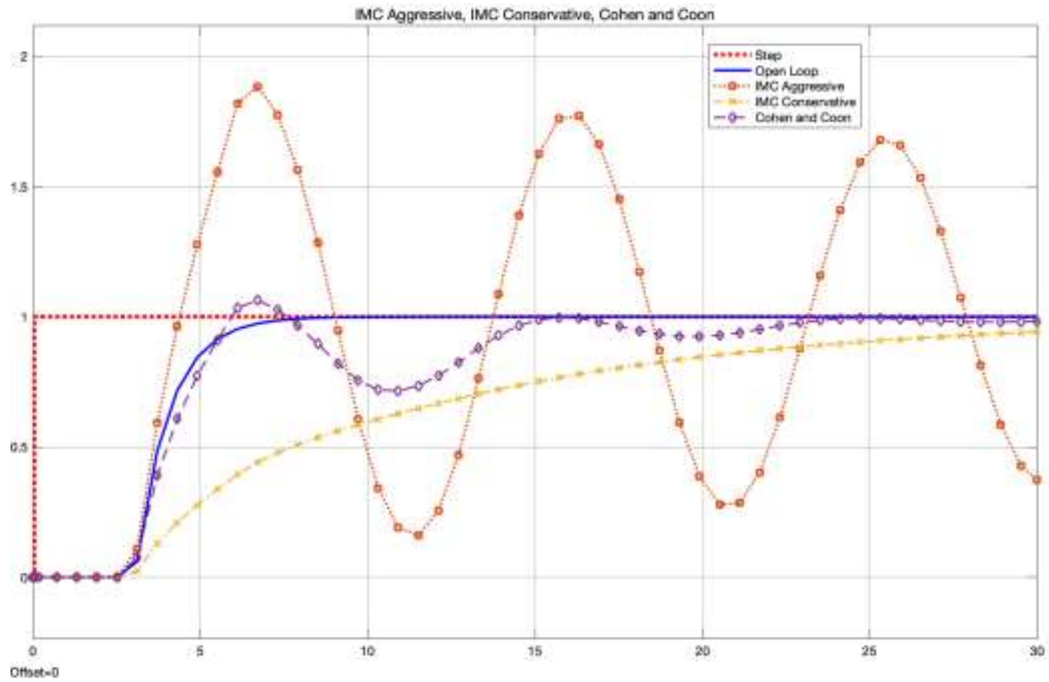
3. Describe **in a few words** the meaning of the FOPDT model

Open loop tuning methods are used to find the optimal PID controller parameters and the closed loop system response is recorded and reported in the attached figure.

4. Which is the best, according to the provided figure, tuning algorithm? (A qualitatively but detailed answer is required)

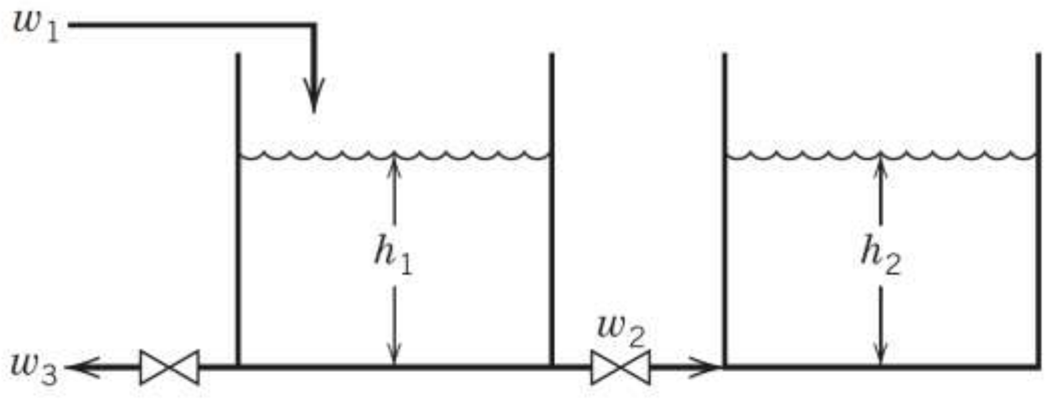
5. According to the best tuning algorithm proposed by you in 4), calculate the tuning parameters of the PID controller.


Open Loop
Step4
Open Loop
Offset=0


IMC Aggressive, IMC Conservative, Cohen and Coon
Step
Open Loop
IMC Aggressive
IMC Conservative
Cohen and Coon
Offset=0

Section 6: MATHEMATICAL MODELLING

Two tanks are connected together in the following unusual way:



- The density of the liquid, ρ, is constant.
- The cross-sectional areas of the two tanks are A1 and A2.
- The two valves are linear with resistances $R_{v2}=R_{v3}=R_v$.

You must:

1. write the **dynamical model** of the system;
2. write the **steady state** model of the system;
3. list **input**, **state**, **output** variables and the **parameters** of the model;
4. is the dynamical model a linear model? If not, **individuate and linearize the non-linear term(s);**
5. **write the model in the Laplace domain;**
6. **obtain the transfer function** describing the evolution of $h_1(s)$ with respect to the input variable $w_1(s)$;
7. **classify the obtained transfer function** and individuate the parameters.